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Visualization of Utility Adjustment Tracking Using GIS

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Visualization of Utility Adjustment Tracking Using GIS

by

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Thesis

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Dedicated to my niece, Gauri Chaudhary

!!She might one day read this!!

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Abstract

Visualization of Utility Adjustment and Tracking Using GIS

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Utility related issues are one of the most common reasons for project delays and project over-budget for highway projects. As the number and complexity of transportation projects increases so does the scope of conflicts between utility facilities and state DOTs. Different state DOTs accept that the utility adjustment process is one of the biggest challenges for the timely completion of a transportation infrastructure project, yet there exist no well-developed methodology or system to track utility adjustment process. Systems that do exist depend too much on displaying unhelpful and non-interactive information. The information provided to the user is non-descriptive, and hence the user cannot contextualize the project. This thesis focuses on developing a methodology which can provide the user with a visualization system for tracking utility relocation projects. This methodology uses relational database and a GIS platform for visualization capabilities. A utility adjustment process was developed for TxDOT to understand the various activities necessary for tracking a utility relocation project; these activities were then used for developing a relational database for storing utility adjustment information. Spatial location data for different utilities was collected using

different GPS systems and then used in a GIS based platform to display these utilities on interactive maps. The relational database and the GIS platform were then integrated so that the user can track and visualize the utility relocation projects. The utility coordinators at Dallas District can verify the soundness and usability of this visualization system after using it.

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Chapter 1 Introduction

Research Motivation

According to the recent studies utility related issues are one of the major reasons for highway project delays (R. D. Ellis 2002). Utility conflicts occur when state Department of Transportation and a utility provider compete for limited space within the ROW (Right of Way). There can be other reasons why utility conflicts occur, but they are beyond the scope of our research.

There are many reasons why utility related conflicts occur, but for the ease of understanding and organizing, utility conflicts are divided into following five categories:

(1) Conflicts due to utility facilities interfering with transportation design features (existing or proposed).

(2) Conflicts due to utility facilities interfering with transportation construction activities or phasing.

(3) Conflicts due to planned utility facilities interfering with existing ones.

(4) Conflicts due to utility facilities being non-compliant with utility accommodation policies.

(5) Conflicts due to utility facilities being non-compliant with safety regulations.

When utility conflicts are not resolved between state DOT and the utility service provider, the utility has to relocate to resolve the conflict. This process is termed as utility adjustment. For the timely delivery of highway construction projects, the utility facilities that are in conflict should be properly adjusted.

The conflicting interests of the parties involved can adversely affect the process of utility adjustment. The key to a successful utility adjustment is constant communication and coordination between the state DOT and utilities. Utility adjustments are not an isolated process. Delays during this stage trickle down through the process and set off a domino effect, causing construction delays resulting in change orders and damage or litigation claims, safety concerns at the job site, annoyance, and poor public perception of the project (Quiroga, et al. 2012).

Utility adjustment process requires a lot of coordination and communication between the parties involved, this coordination and communication generate a large amount of data and documentation. Utility coordinators at the DOTs are responsible for managing this large amount of incoming information and keep the utility relocation process within manageable limits. As the number of transportation infrastructure projects increase both in numbers and complexity, it becomes extremely difficult for utility coordinators to manage the utility adjustment process and keep the transportation costs within assigned budgets.

Due to large investments in public infrastructure, transportation projects are coming thick and fast; combine that with a large amount of information management required for coordination and communication in a utility adjustments process; utility coordinators are overwhelmed. The utility coordination is not a straight forward continuous process, and there can be prolonged periods of no activities. The utility coordinators have to keep track of all these projects and their status which can be very laborious.

RESEARCH OBJECTIVES

The process of utility adjustment is strenuous as well as repetitive. Combine this with strict deadlines for transportation projects; this makes the utility coordinator's job very stressful. The best way of managing a utility adjustment project is to have a very robust coordination with all parties involved. The utility coordinators must ensure that the information does not overwhelm them so that they can look through the most relevant aspects of the utility adjustment process.

People, in general, are visual beings. It makes more sense to them, and it is easy for them to contextualize any information if they can visualize it in real time. Equally important is to organize data in some structured form for people to make sense of it. Therefore this research focused on developing a method which is based on well-defined information flow model, can effectively manage information and then display the information in an interactive way.

The goal of this research was to develop a method which was highly structured yet very robust, can store a sizeable amount of data yet still be easily available to everyone and finally should be able to provide users with results that can be visualized geographically rather than just words and numbers. These research goals were accomplished by fulfilling the sub-objectives of this study. The sub-objectives included:

(1) Review of informational flow model of utility adjustment process.

(2) Review of relational database used for utility adjustment and tracking.

(3) Gather geographical spatial data for utility facilities.

(4) Integrate GIS and relational database for visualization.

(5) Develop the GIS visualization system

RESEARCH SCOPE AND LIMITATIONS

The primary aim of the GIS visualization system was to assist the utility coordinators at TxDOT to manage the utility relocation projects efficiently. The system as a whole focuses on storing project related information, tracking utility adjustment activities, recording utility company and personnel information and displaying all this information in an easy to use interactive and user-friendly environment.

Although the development of the system itself involved many technical challenges, the system does not take into account technical aspects of utility conflict resolution. The main aim of this system was to organize and display the information in a timely and effective manner which will help the utility coordinators to manage utility relocation projects.

While developing this system the main suggestions and recommendations were coming from the users at TxDOT. Therefore this system provides information that would be beneficial to TxDOT users like utility coordinators, engineers and project managers. Utility companies can also use this tool after making some changes, but this tool is geared towards the need of TxDOT utility team.

READERS GUIDE

The Thesis is organized into Seven Chapters. Chapter 1 discusses the motivation, objective, scope, and organization of this thesis. Chapter 2 provides a research methodology followed in this research for developing a visualization method for tracking utility adjustments. Chapter 3 discusses the literature review done on topics of utility adjustment, the impact of utility adjustment on construction projects, methods of locating underground utilities and progress in the field of geographical information system (GIS).

Chapter 4 presents a review of the utility adjustment tracking process. Chapter 5 details how utility adjustment tracking system is integrated with GIS and how shapefiles are developed. Chapter 6 discusses the development of GIS-based visualization system. Finally, Chapter 7 provides the concluding remarks for this research and potential for improvements and future work.

Chapter 2 Research Methodology

This research is divided into five major steps, as shown in Figure 2-1: (1) Conduct a Literature review; (2) Review the Utility Adjustment Tracking Tool (UAT); (3) Integrate Utility Adjustment Tracking Tool with GIS and develop the shapefiles; (4) Construct GIS Visualization System; (5) Draw conclusions and recommendations.

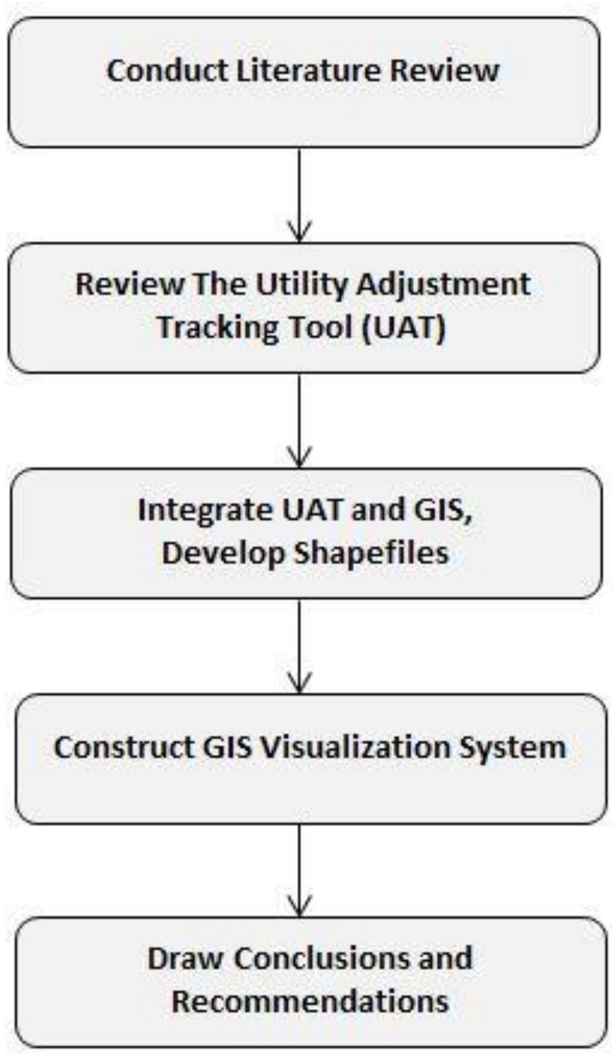


Figure 2-1 – Flow Chart of Research Methodology

CONDUCT LITERATURE REVIEW

A comprehensive literature review was done to acquire knowledge about the utility adjustment process in general and utility adjustment process followed by TxDOT in particular. The literature review involved a detailed understanding of various TxDOT manuals like project development manual and right-of-way utility manual. User manuals of various TxDOT systems like UIRS and PLRS etc. were studied to understand design basics of these systems and the type of information provided by them. Reviewing these user manuals provided us with an elementary design concept for our utility adjustment tool. The author also reviewed other publications on new systems which were under development; for tracking sub-surface or overhead utilities to understand how to gather geographical data for the utilities. The literature review helped us to understand the utility process in detail and provided us with a strong foundation for developing a method for visualizing utility adjustment tracking process. Synopsis of the literature review is present in Chapter 3

REVIEW THE UTILITY ADJUSTMENT TRACKING SYSTEM

Our literature review pointed out that there exists an information flow model at TxDOT for utility adjustment process, but it is not used widely because of its complex nature, and an alternate information flow model has also been developed keeping the original model as the base point. The major benefit of this newly developed information flow model was that it clearly demonstrated the 22 critical activities necessary for tracking a utility adjustment project. The development of a new information flow model as well as understanding 22 critical activities resulted in the developing of a new system necessary for tracking the utility adjustment process. The utility adjustment and tracking tool is a relational database built on MS access platform. MS access is part of Microsoft Office Suite and hence easily and readily available. Also, it can easily interact with

Microsoft Outlook mail server, it is very easy to use, and development of the tool does not require a great deal of coding. The construction of the system was divided into two layers (Hura and Singhal 2001): (1) Data access layer; (2) The presentation layer. An entity relationship diagram was developed (ERD) to provide a basic blueprint of how the information will interact inside the system. ERD is usually defined upfront so that the database design can be finalized as early as possible since changing design at a later stage can result in other complications like data corruption or security related issues. User interface development is necessary so that the targeted users can easily operate the system without having to understand the complex logic working at the back end of the system. The user interface development included (1) Development of forms: Forms are used by the user to enter information into the system; (2) Reports: Reports are used for organizing and displaying the information present in the system in a way that helps the utility coordinators. Chapter 4 discusses the utility adjustment tracking tool in detail.

INTEGRATION OF UAT WITH GIS AND DEVELOPMENT OF SHAPEFILES

The utility adjustment tracking system was developed as a stand-alone tool for tracking of utility adjustment process. The utility coordinators at TxDOT used it for pilot runs for tracking relocation projects and provided positive feedback and recommendations. They also suggested that the system required inputting too much information and the user interface for displaying the results was very monotonous. It was decided to develop a method; that provided the user with more interactive and visually pleasing user interface for displaying the results. An exhaustive review of various systems and software available in the market which can be integrated with relational database based system and displays the relevant results in a real-time geographical information based environment. The research team selected the GIS system because of its integration capabilities with almost all the database systems available in the market and better user interface than all other spatial systems. The process of integrating UAT and GIS is detailed in Chapter 5. The next step in the development of the visualization tool was collecting geographical spatial data for utilities. These location coordinates were further used for developing utility information shapefiles for GIS system. A detailed analysis was done on what kind of output does the user of the system requires, based on the results of this analysis number of shapefiles were determined. Shapefiles were developed which would provide all the information that a utility coordinator might require. Advanced GPS systems like Trimble R10 GNSS system were used along with Google Pro Earth for establishing the exact locations of the utilities. There is no well-defined process for gathering utility related spatial data; so the research team innovated using latest technology and software. The details of data collection and development of shapefiles has been explained in Chapter 5.

CONSTRUCT THE GIS VISUALIZATION SYSTEM

The main priority while developing the GIS visualization system was; that the system should not be complicated and a user with very limited knowledge of GIS should be able to use the system. For this purpose, the number of shapefiles was kept to a minimum so as not to confuse the user and to keep navigation between different objects in the system easy. The user interface of the system was developed next; different layers, tables were present in the system, and the user can simply navigate between them to see all the information related to utility adjustment process. The geographical data displayed was annotated so that the information displayed was more descriptive and interactive. Different buttons were created on the system so that the user can directly use the inbuilt functions of the GIS system rather than using the toolbar. Pre-defined dynamic reports were also developed to be used by the utility coordinators. A reporting tool was also created so that the user can customize reports according to their requirements. The development of GIS-based visualization system in discussed in Chapter 6.

CONCLUSIONS AND RECOMMENDATIONS

Chapter 6 summarizes this research and draw conclusions based on the research conducted. This chapter further elaborates on how we can further develop this visualization system and provides recommendations for the future.

Chapter 3 Literature Review

This chapter focuses on discussing the utility conflicts and utility adjustment process in general and discusses various relevant issues that impact the process of utility relocation. Schedule and monetary constraints affecting the utility adjustment process and how they impact the utilities are also discussed. Some methods that are being used for locating utility facilities are briefly described and a brief description of how the GIS architecture has evolved over time is also provided.

UTILITY ADJUSTMENT OVERVIEW

Utilities are also the legal occupants of the right-of-way, and they do not violate TxDOT right-of-way. The above has been made clear in TxDOT ROW Utility Manual (Texas Department Of Transportation 2014). The need and safety of the traveling public are of the most important concern, and the rights of utilities are subordinate to them. According to the ROW Utility Manual if a transportation construction project results in utilities having to relocate from their current position; then, in that case, it's the primary responsibility of TxDOT to notify all the utilities that need to be relocated. It is also the responsibility of TxDOT to co-ordinate with all the utility owners during the utility adjustment process. The onus of moving their facility, cost impact assessment, improvements, locating, preparing relocation designs and contracting the work is on the concerned utility company (Texas Department Of Transportation 2013). To achieve the targeted letting dates, TxDOT utility coordinators maintain coordination with all the utilities involved in the project to track the status of the utility adjustment process. The regular coordination also helps to (1) Achieve the targeted utility adjustments at minimum cost and delay; (2) Safety of traveling public, TxDOT personnel and utility personnel; (3) Protecting utility facilities and transportation infrastructure; (4) Achieving targeted letting dates.

SCHEDULE AND MONETARY OUTLOOK OF UTILITY ADJUSTMENT

A typical highway construction project can take somewhere between 9 to 19 years to complete; starting from the time of envisioning the project to actual completion of the construction (United States General Accounting Office 2002). The highway project can be time-consuming and over budget than initially estimated and may require additional resources from both TxDOT and other stakeholders like utilities and project owners. There are four stages in project lifecycle of a highway project. The Four stages are as follow: Stage 1 - Planning; Stage 2 - Preliminary Design and Environmental Review; Stage 3 - Final Design and ROW Acquisition; Stage 4 - Construction

As can be easily understood from the four stages, in case utility relocation has to be done during the project it would be performed during the third stage of the project. It is important to understand the utility relocation should be completed before the project letting date.

Utility Owners are responsible for relocating their facility, preparing their schedules, cost estimates and letting the relocation project to a sub-contractor (TXDOT 2014). There are certain exceptions where TxDOT will pay for utility relocation cost. If TxDOT is paying for the utility adjustment, such type of utility adjustment is called "Reimbursable project." If the owner has to bear the cost of utility adjustment process, it is called "Non-Reimbursable Project." A utility adjustment can be classified as "Reimbursable Project" if (1) Highway project has federal funds; (2) Utility owner has compensable property interests. In the event of a federally funded project, both utilities with and without compensable property interest are eligible for cost participation by the state DOT according to Part 645 of the 23 Code of Federal Regulations (23 CFR) (Code of Federal Regulations 1999). If a utility owner claims its compensable property interest, TxDOT pays for purchasing new utility easements and cost of adjusting the utility facility. There are many utility adjustments that are partially reimbursable. The eligibility ratio determines this partial reimbursement. The eligibility ratio of the utility is usually mentioned in the agreement assembly upfront (O'Connor, et al. 2006)

UTILITY ADJUSTMENT PROCESS FLOW FRAMEWORK

The utility adjustment process flow framework currently used by TxDOT has 27 activities associated with it. According to TxDOT Utility Coordinators; "The utility adjustment process for a transportation infrastructure projects tends to be very lengthy and demanding process" (Kraus, Cesar Quiroga and Koncz 2007).

The district or area office informs the utility coordinator about the project development; this marks the beginning of the utility adjustment process. The utility coordinators then identify the utility companies that have their utilities in the vicinity of the proposed project. There are different methods of identifying the utilities like walking around the project site, using one-call services or using as-built submitted by utilities. As a general rule utility coordinators tend to use all three methods for identifying the utilities on a project site. After identifying all the utility companies, the next step is to determine the status of ROW acquisition and the source of funding. The utility companies identified are thus notified of the project, and a meeting is organized to determine which of the identified utilities are in conflict. TxDOT assigns all the utilities on the project U/P number. This U/P Number is a unique number for each utility on the project. TxDOT utility coordinators provide each utility company with a schematic design so that each utility can perform their utility conflict analysis and determine if they are in conflict or not. After all the companies are done with the utility conflict analysis, the utility coordinators then proceed to develop a conceptual utility adjustment plan for conflicting utilities. At this point, the utility coordinators are confident of having figured out all the utilities that are in conflict.

The next phase of utility adjustment process begins with kick-off meetings with all the conflicting utilities. In this meeting, TxDOT shares 30% roadway design plans with the utilities so that they can come up with their relocation plan and schedules for utility adjustment. The utility coordinators then send officially certified letters to utilities stating their conflict with the project and requesting design and preliminary cost estimates. The next step is to provide utility companies with agreement assembly forms and links to utility accommodation rules (UAR). At this point in utility adjustment process, TxDOT provides utility companies with 60% roadway plans so that utility companies can prepare their final design plans, cost estimates, and schedules. The TxDOT utility coordinators review all these design plans, cost estimates, and agreement assemblies; if utility coordinator is not satisfied with these plans they can ask utility companies to resubmit the design plans, cost estimates, and agreement assembly again after making necessary changes. If the design plans and cost estimates are acceptable final agreement is executed, and notice to proceed is issued to the utility companies.

The utility companies then begin the actual utility relocation process in the field; this process is monitored continuously by TxDOT utility coordinators and project managers. If the project manager thinks that the utility relocation work performed by the utilities is as per agreement it is deemed acceptable and utility company is asked for as-built and final billing; in case the work performed in not per agreement utility will have to perform re-work as per TxDOT satisfaction. When the as-built plans are submitted by the utility company to TxDOT, it marks the end of utility adjustment process

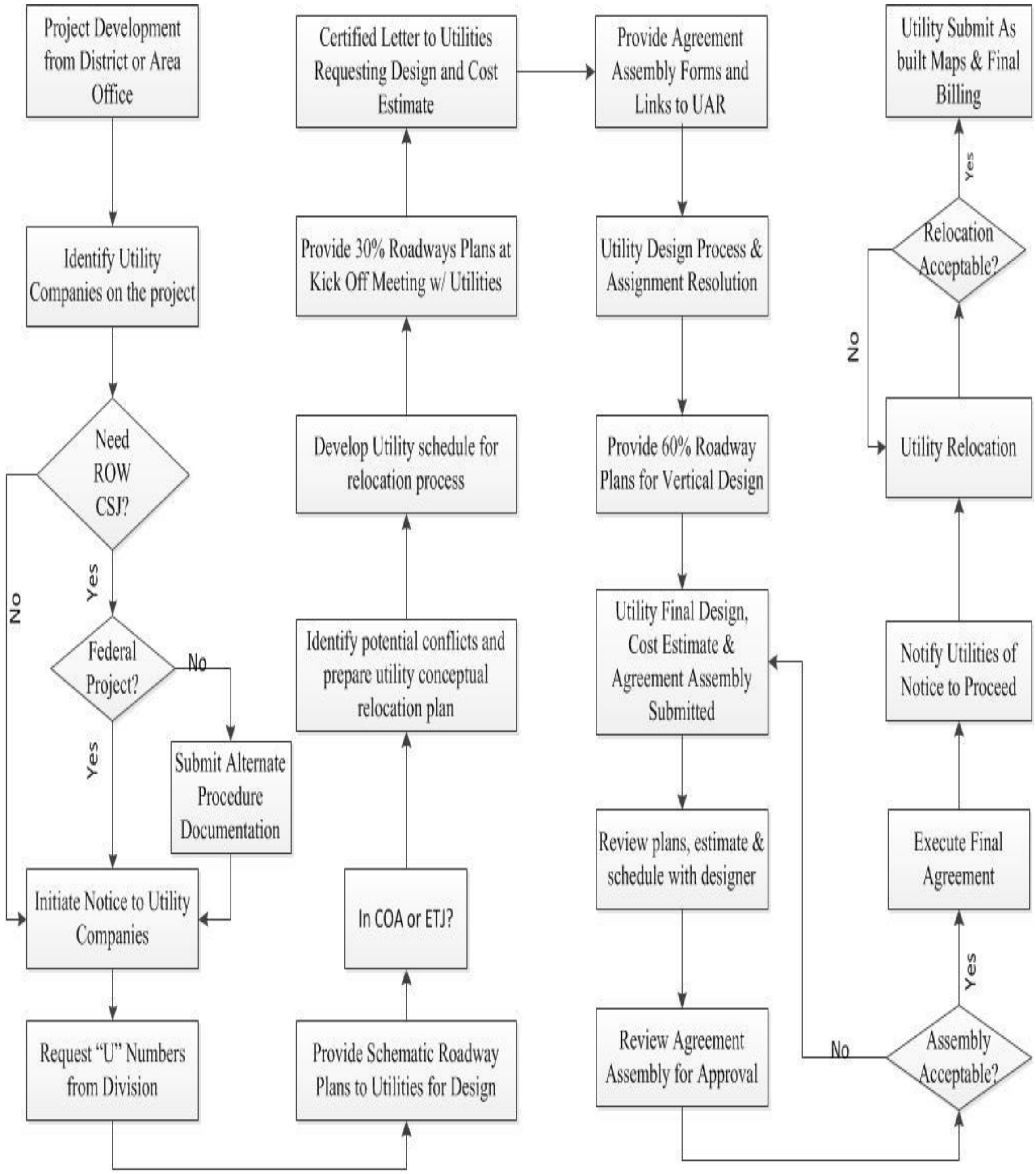


Figure 3-2: Current Utility Adjustment Process Flow Framework (Kraus, Cesar Quiroga and Koncz 2007)

IMPACT OF UTILITY ADJUSTMENT DELAYS

Utility Adjustment delays have a major impact on both cost and schedule of a highway project. The cost and schedule impact of utility adjustment has been discussed in this section.

Utility adjustment related issues are primary sources of delays on a highway construction project (Arboleda, et al. 2004) (R. D. Ellis 2002). Utilities often act as physical barriers to the construction of highway projects and these utilities need to be relocated before the construction project can be completed. Utility adjustment delays can have both direct and indirect impact on project schedules. These delays in the completion of highway projects result in inconvenience and safety risks to the public as well as the higher cost to state DOTs (Chou 2007).

The total cost of the project is directly impacted due to schedule delays in the highway construction project. To offset this cost due to project delays the contractors include this cost in their preliminary cost estimates and bid price. Some state DOTs have made regulations by which they can compensate the contractors in case of utility delays but still there are inflated bids by the contractor due to unknown nature of utility adjustment delays. The net dollar amount resulting from contract claims due to utility adjustments can be fairly large.

METHODS OF UTILITY FACILITY LOCATION

Over the year's utilities, specifically, underground utilities have proliferated within the right-of-way of many highway projects. The exact location and nature of these sub-surface utilities have not been documented. The presence of these utilities particularly in the right-of-way of the highway projects has presented the state DOTs with a distinct challenge of ensuring public safety while relocating these underground utilities. (SHRP 2012).

Not all underground utilities are similar in materials, sizes, depths, conductivity, ground conditions, surface obstacle, etc. which necessitates the use of multiple utility locating technologies to acquire their exact location. There are times when different methods are used in tandem to determine the exact location of these underground utilities. There are some technologies that are being used by utility companies for accurate determination of their utilities. This section details some of these technologies:

Global Positioning System (GPS): This is the simplest and most economical method of mapping underground utilities. Typically the GPS uses RTK fixes and local reference stations or reference network corrections to provide the user with highly accurate positional data. By collecting the visible points of a utility using GPS we can accurately map the underground utility. One of the drawbacks of this technology is the readings of the system can be affected by obstructions, multipath, reference station precision. Large buildings and a wall can obstruct the signal, and even trees can impact the strength of GPS signal resulting in inaccurate readings. This technology needs open spaces to work better (Roberts, et al. 2007)

Ground Penetrating Radar (GPR): This method of mapping of underground utilities is one of the most accurate methods of mapping. GPR is an excellent tool for imaging and mapping steel reinforced pipes and HDPE pipes (used for Water, waste-water, Gas pipelines, well heads, electrical and telecommunication conduits) under soil or concrete ground. (Thitimakorn, et al. 2016). GPR uses high-frequency radio signals that are transmitted into the ground and reflected signals are returned to the receiver and stored. The computer then measures the time taken for the pulse to and from the target which tells us the depth and location. GPR waves travel through many different materials. Different types of soil, concrete, fill material, debris, and varying amounts of water saturation all have different dielectric and conductive properties that affect the GPR waves, and thus GPR data interpretation. To understand the data obtained from GPR the user should be aware of the working principal of GPR system and should have a good background in geotechnical science.

Array of Induction Receiver (AIR) System: This system is one of the most widely used systems for detecting and mapping underground utilities. The system is based on electromagnetic measurement techniques and uses the same basic principle as radio detection devices. One of the drawbacks of using this system is that you should be able to see at least one end of the utility to send electromagnetic signals through the utility. An electric current is induced in a subsurface utility line; the induced current produces a magnetic field that is detected at the surface. The AIR system provides 48 simultaneous magnetic field measurements over an 8 feet swath. The magnetic field data is typically collected on 1’ x 1’ grid spacing over the entire survey area. The position of the AIR system is tracked using an accurate positioning system such as a robotic laser tracking system which provides centimeter position accuracies. The data is stored on a computer and then processed using advanced electromagnetic modeling techniques (SHRP 2 Trenchless Technology center n.d.).

Low-Frequency Conductive P/C Locator: Pipe and cable locators are the most common instruments for both detecting and tracing underground utilities. There are many manufacturers of this type of equipment, and hundreds of separate pieces of equipment. Variations in equipment include antenna size, antenna shape, number of antennas, frequencies of antenna output, thresholds of signal output (automatic or controlled gain), types of signal displays, types of various attachments, indirect depth measurement indications, current flow direction indications, signal strength displays, and shape, size, and weight of transmitters and/or receivers. All pipe and cable locators have one or more receiving antennas, and, if they are an active device, they will also have one or more transmitting antennas. The size, shape, and type of antenna are directly related to its efficiency in receiving a signal of a certain shape and frequency. Pipe and cable locators are used for both detection and tracing of utilities.

DATABASE MANAGEMENT SYSTEMS (DBMS) AND GIS

GIS is a very sophisticated system used for maintaining and analyzing geospatial data. As the amount of information to be analyzed increased and new functionalities were added to the GIS system the role of Database management systems (DBMS) in GIS became very important. The capability of a GIS system to provide usable information depends on the logical consistency and integrity of the data being used by GIS; this is where DBMS systems are important since they can handle large volumes of data and can ensure logical consistency and integrity of the data in the system. Many organizations now days want GIS functionality as part of inbuilt services for their Project management systems where spatial data and alphanumeric data are maintained in one integrated environment. Hence in this new age, GIS systems DBMS systems like Oracle, SAP and MS-Access occupy a central place. The evolution of GIS architecture to integrated DBMS data can be understood in 3 basic steps: (1) Dual architecture consisting of separated data management for administrative data in a relational database and spatial data in GIS; (2) All data stored in one single RDBMS, a middleware was maintained since the DBMS system at the time did not support the spatial data (3) Presently most mainstream DBMS support spatial data types and spatial functions by means of abstract data types (ADTs). All data is maintained in one single RDBMS system ((Zlatanova and Stoter 2006).

Chapter 4 Review of Utility Adjustment Tracking System

The main aim of this research was to develop a system which would help in the visualization of the complicated utility adjustment process. To achieve this aim, it was necessary to understand the key activities that impacted the utility adjustment process This chapter gives a brief overview of the utility adjustment tracking system which will help the user to understand the basics of the visualization system. The utility adjustment tracking system is an important part of the visualization system hence readers should understand the basic functionality and working of the utility adjustment tracking system.

ACTIVITIES TRACKED IN UTILITY ADJUSTMENT PROCESS

The key activities necessary for tracking of utility adjustment process can be understood by investigating the utility adjustment process flow framework used in practice by utility coordinators. There is a considerable difference between the process flow framework described in TxDOT Utility manual and the one used by the utility coordinators. According to Utility coordinators, there are certain activities in the utility adjustment process flow framework that is not performed by utility coordinators and thus tracking them in the tool will not be any benefit to them. The new process flow model; used by the team that developed the utility adjustment tracking system included only those activities in which utility coordinators are involved (Shetty 2015).

This proposed utility adjustment process flow model had 21 activities that were necessary for tracking the utility adjustment process. Some of these activities happen over a long period and hence had to be divided into different activities to track them effectively. Table 4-1 shows the list of activities necessary for tracking the utility adjustment process.

Sl.#	Activities Identified For Tracking
1	Identify utility companies on the project
2	Identify potential conflicts
3	Prepare utility conceptual relocation plan
4	Plan review meeting
5	Mail certified notification letters to utility companies
6	Kick-off meeting
7	Provide agreement assembly and links to the utility companies
8	Request relocation plan, design, and cost estimate from utility companies
9	Receive of relocation plan, design and cost estimate from utility companies
10	Review of relocation plan, design and cost estimate for compliance
11	Determination of requirement SUE levels A for utility companies
12	Check for joint bid
13	Provide 60% roadway plans for vertical design
14	Check for exceptions
15	Receipt of final agreement assembly, relocation plan, design and cost estimate from utility companies
16	Review of agreement assembly for approval by utility coordinator
17	Submit agreement assembly for approval at first-level division
18	Execution of final agreement
19	Coordination meeting
20	Monitor and inspect utility construction
21	Final billing
22	Submission of as-built plans by utility companies

Table 4-1: List of Activities Identified for Tracking (Shetty 2015)

SYSTEM LOGIC

The utility adjustment process is a complicated process which involves coordination between multiple utility companies over multiple projects. The utility adjustment tracking system has performed effectively in multiple project environments. To track the utility process, the system stores information about utility facility companies, utility conflicts, TxDOT offices and events associated with the adjustment process.

As discussed utility adjustment process is a complicated one; the key to effectively managing utility adjustment process is better coordination and communication between multiple parties and then organizing the information in a meaningful way that will help us to track all the information across all projects. Every effort done by a utility coordinator to complete an activity (22 activities defined in proposed utility adjustment process flow) is an event. Tracking an event helps to track the utility adjustment process for a project. Now there can be multiple utilities that have to be adjusted in a single project. For each utility, the coordinators have to track 22 activities, and each activity can have multiple events associated with them. Imagine the scenario where one utility coordinator has to manage multiple projects. This scenario has been well addressed in the utility adjustment system by having a hierarchy of various components of utility adjustment process. The logic of utility adjustment tracking system consists of four components:

(1) Project - the proposed highway project that causes utility conflicts.
(2) Activities - The 22 major activities of utility adjustment process shown in the table above serve as the standard template in the system.
(3) Events –the continuous communication and coordination efforts that are needed to ensure the completion of an activity of the utility adjustment process. The events

are not limited to a certain number per activities and can be as many as it takes to ensure the completion of said activity.

(4) Action items – a task accomplished by an individual or a small group following a decision at a certain event

Figure 4-2 shows the hierarchical relationship between these four components. A project consists of 22 activities defined in proposed utility adjustment process. Each activity further has some events associated with it that are necessary for completion of the activity. It is important to understand that the number of events in an activity is not fixed and is at the discretion of the user of the system. Each event can have further action items related to it.

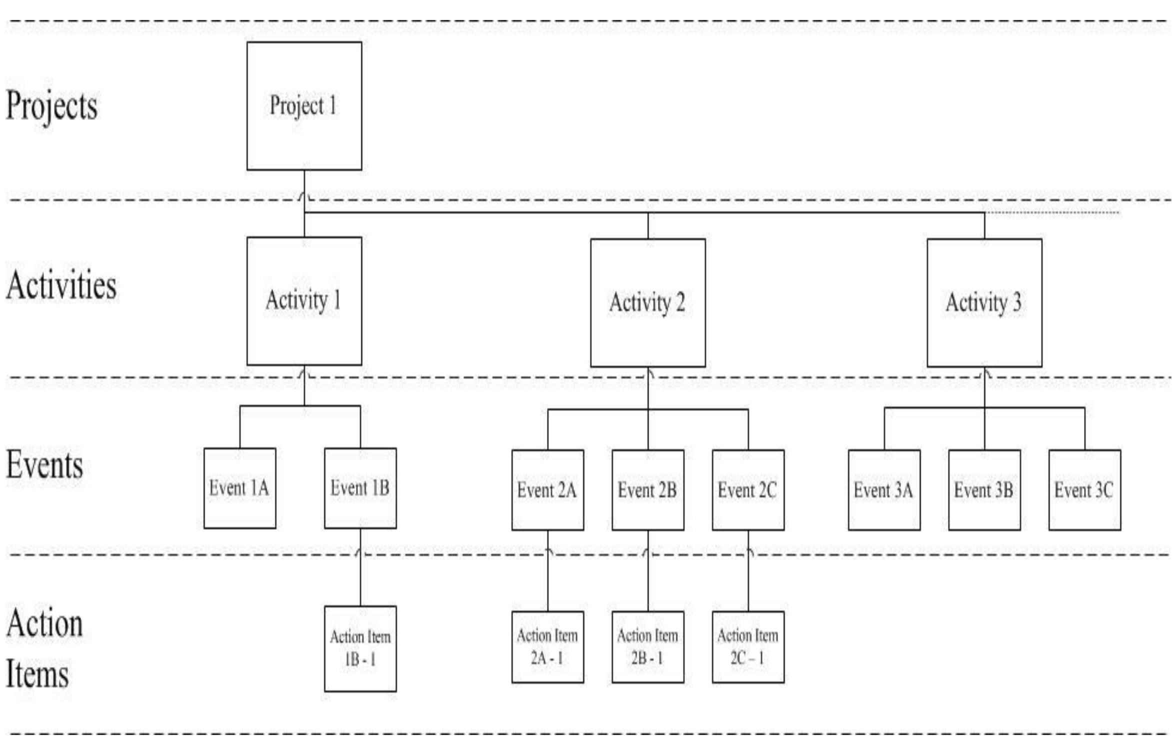


Figure 4-2: Hierarchical Relationship Diagram (Shetty 2015)

Data Redundancy is a very common problem with most of the database systems. Data redundancy can cause data inconsistency, inefficient database, and data corruption. The problem of data redundancy has also been handled very well in this system.

BACK-END OF THE SYSTEM

Developing a database is not a one-time step by step process; but rather an iterative one in which multiple tasks are performed iteratively. Following are the five steps: (1) Identification of entities of the database; (2) Identification of attributes of entities; (3) Relationship identification; (4) Assign Keys and (5) Normalization to reduce data redundancy.

Entities and Attributes

In simple words, an entity is defined as a collection of similar objects or things in a database capable of existing independently and can be uniquely identified. Utility Company and Project are two different things and hence different entities. In a database, the entity is represented as tables of the database. The utility adjustment tracking system has 24 entities. Table 4-2 shows all the entities in the database

The attribute is defined as the property of an entity, and an entity usually, has more than one attribute. For UTIL_FCLTY entity UTIL_FCLTY_SZ (size) and UTIL_FCLTY_DEPTH (depth) are some of the attributes. While developing a database clear and concise understanding is required for defining the attributes of an entity. The columns of database tables are its attributes.

Sl. No	Entity in system	Information represented
1	ACTIVITIES	Project - Utility Adjustment Activities
2	ATTACHMENT	Documents/File
3	CMPNY	Utility Company
4	CMPNY_OFFC	Utility Company Offices
5	CMPNY_USER	Utility Company Personnel
6	DOT_OFFC	TxDOT Offices
7	DOT_PROJ	Highway Project
8	DOT_USER	TxDOT Personnel
9	ESTMT	Estimated amount to resolve conflict
10	EVENT	Events
11	EVENT_ACTION	Action Items
12	EVENT_ACTION_PERSON	Person in charge of Action Items
13	EVENT_CAT	Category of Events
14	EVENT_PART	Event Participants
15	EXCPTN	Exception
16	JOINT_BID	Joint Bid
17	STD_ACTIVITIES	Standard - Utility Adjustment Activities
18	UTIL_AGRMT	Utility Agreement
19	UTIL_BILL	Utility Payment
20	UTIL_CNFLT	Utility Conflict
21	UTIL_CONSUL	Utility Consultants
22	UTIL_CONSUL_PERSON	Utility Consultant Personnel
23	UTIL_FCLTY	Utility Facility
24	UTIL_FCLTY_TYPE	Utility Facility Type

Table 4-2: Entities in Utility Adjustment Tracking System (Shetty 2015)

Entity Relationships and Assigning Keys

In database; entities have relationships between each other. For example, a conflict may have many activities associated with it, and each activity might have many events to it. The relationship between two entities can be one-to-one, one-to-many, many-to-many; this is called cardinality of the relationship. Understanding cardinality is important for maintaining the integrity of the data collected.

There are two types of keys used in utility adjustment tracking system: (1) Primary Key is a unique identifier for an entity. The primary key is made up of one or more table columns whose value uniquely identifies a row in that table. (2) Foreign Key identifies how a table in related to another table. Two tables have same data column which acts as a bridge between the two tables for querying purposes. This column is a foreign key.

Data Redundancy

Controlling data redundancy is very important in a database system. Data normalization is a process of organizing data attributes within a data models to increase the cohesion of entity types (Peter and Coronel 2007). Data normalization helps in storing information in only one place and thus avoids data duplication and helps in system stability.

FRONT-END OF THE SYSTEM

An aesthetically pleasing and easy to navigate user interface is an essential part of a good database system. This user interface is also called front end of the system. The utility adjustment tracking system uses various forms and reports to have a better user interface.

The forms in the utility adjustment system are used for entering and editing information, displaying information and navigation purposes. There are some forms that are embedded in other forms; these subforms have a parent-child relationship with the main form. There is a total of 37 forms in the utility adjustment tracking tool. The first form the user sees when they open the tool is the welcome screen shown in Figure 4-3. A welcome screen is a navigational form used for navigating to the four main options: (1) Menu; (2) Reports; (3) Quick Status and (4) Quit. The user needs to click any of them if they want to navigate to the respective options. Quit button is used to save and close the utility adjustment tracking tool.

Figure 4-3: Welcome Screen Form

The Menu option is used to navigate to the menu form; this menu screen is used for saving all the information about the project, utilities, utility personnel, utility facility, utility conflict, utility agreement, standard utility adjustment activities, and event information. For maintaining the aesthetics of the user interface the menu screen is divided into three categories which use similar information: (1) General Information;

(2) Utility Information; (3) Utility Adjustment Tracking. There are further options in each of these categories; clicking any of these options takes the user to a specific form where the user can enter or view the information stored in the system corresponding to the option. Figure 4-4 shows us the menu form.

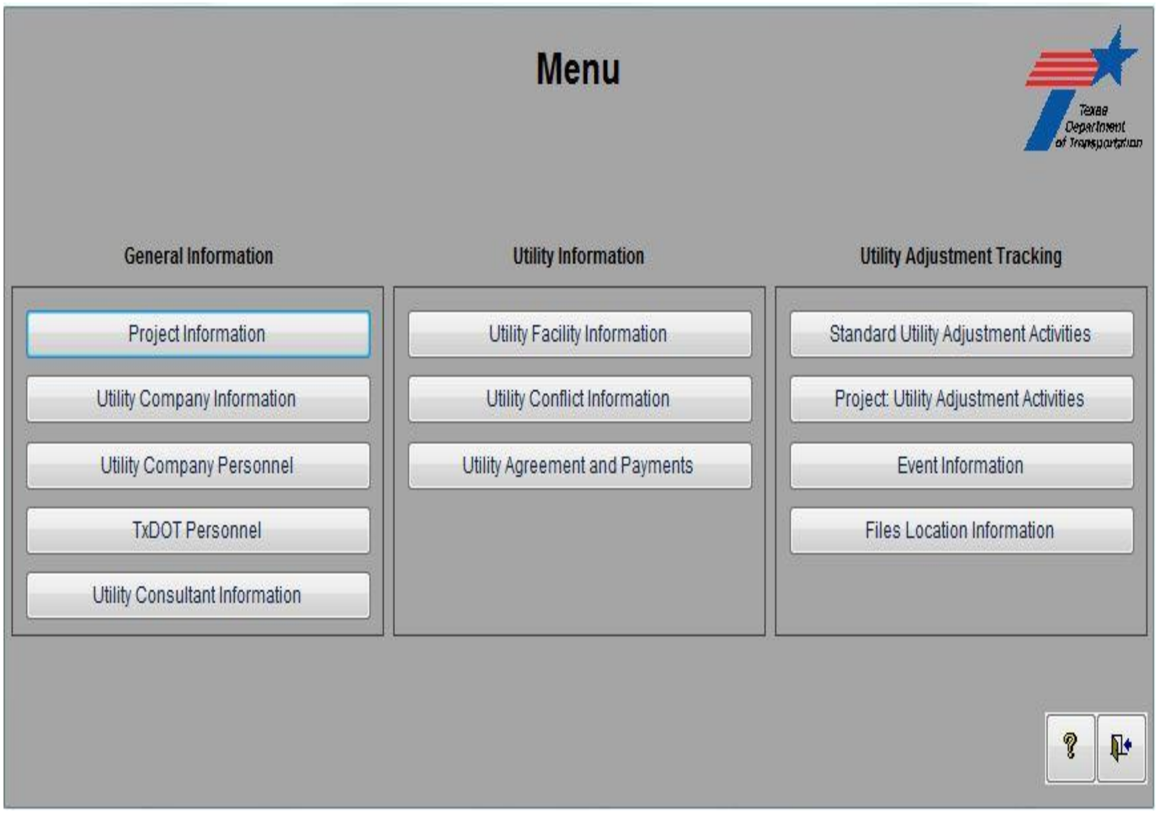


Figure 4-4: Menu Screen Form

The second option on the welcome screen is "Reports" option and clicking on this option opens a report form as shown in Fig 4-5. This reports form displays five customized report options, and the user can click on any option to see the report that interests them. This reports form is predominantly a navigational form where user can easily navigate between these 5 customized reports: (1) Conflict Report; (2) Agreement

Status; (3) Progress Report (U Number); (4) Progress Report (Event Level); (5) Unresolved Conflict Status (Company).

Figure 4-5: Reports Form

Reports provide the user with aesthetically pleasing and reader-friendly format which allows the user to organize better the information that needs to be displayed. The main aim of these reports is to provide the TxDOT Utility consultants concise information about the conflicts on a particular project, conflict information about a particular utility and adjustment status of a utility facility, etc.

The first report in the reports form is the conflict report which provides user information on all the utilities that are in conflict for a particular project. The parsing variable for this report is the project number. The second option on the report form is the agreement report which provides us information on status all the agreements for a particular project. The parsing variables for this report are TxDOT office, project CSJ, Utility Office and Agreement status. By entering the information for the above variables, the user can generate an agreement report.

The third option on the report form in Project Progress Report which displays information on the progress of each utility in a project. The parsing variables for this report is project number. This report is particularly important for utility coordinators if they want to see which utility is not going to meet the schedule relocation deadline and can then coordinate more effectively with the particular utility.

There are two other reports Utility Facility Progress Report which tracks the progress of particular utility in a project. The Unresolved Conflict Report views the unresolved conflict between a utility company and TxDOT. The parsing variable for this report is the utility company and TxDOT area office. This report is useful if the utility coordinators want to have a one-time discussion to solve all the outstanding conflict between TxDOT and a utility company.

Chapter 5 Integrate GIS with UAT and Development of Shapefiles

The main aim of the visualization system is to display the information stored in the utility adjustment tracking system in a visually pleasing and an interactive environment. A thorough investigation on this was done; the result of this investigation was that a GIS (Geographical Information System) based front-end user interface should be developed that can present the information in utility adjustment tracking tool to the user in an aesthetically pleasing way.

Extensive literature review of various GIS systems available in the market was performed, and systems were rated according to their availability, price, and ease of use. There were a couple of GIS software programs that suited our requirements. The methodology used here to develop a GIS-based visualization system can be employed to most of the GIS systems available in the market with some minor changes. The GIS-based user interface was developed in five main steps: (1) Integration of GIS and Utility Adjustment Tracking Tool; (2) Geographical Locational data collection for utilities; (3) Development of Shapefiles; (4) Developing the front-end of the visualization system; (5) Developing the back-end of the visualization system; (6) System reports. This chapter details the first three steps involved in the development of the GIS visualization system. The next three steps are detailed in Chapter 6.

INTEGRATING GIS AND UTILITY ADJUSTMENT TRACKING TOOL

The first step in developing the visualization system was to integrate the information in the utility tracking tool with a system which can process the geographical locational data. The utility adjustment tracking system was developed in Microsoft office MS-Access 2010 platform. The overview of this system is provided in Chapter 4 of this thesis. The MS-access system is a database and has no geographical location data processing capability; although it can store the locational coordinate data. For processing geo-locational data, a GIS-based platform was used, and the utility tool was integrated with it.

System and Software Requirements

For integrating a relational database like utility adjustment tracking system with a GIS platform the computer system should have access to GIS-based software and a relational database. The system should also have an Open Database Connectivity driver (ODBC) for the relational database being used. The ODBC driver should allow GIS software to locate table and query tables in the relational database and allow the GIS platform to retrieve any desired information. To determine if the user has an ODBC driver; click the control panel and double click on the ODBC driver icon and search for the respective relational database driver.

Connecting GIS to Utility Adjustment Tracking System

Object Linking and Embedding Database (OLE DB) is a standard for sharing data between various applications (ESRI, Arc-GIS for Desktop 2016). By enabling an OLE DB connection between the database and GIS, we can view the database tables and queries in GIS environment. The tables and queries viewable in GIS environment should never be edited in the GIS environment; the modifications or editing should be done in a relational database to maintain data integrity. The OLE DB connection was used while using a non-geodatabase (Database that does not have geographical information data) and all the geodatabases were added directly to the GIS environment.

Most of the GIS-based software available in the market can be easily integrated with the utility adjustment tracking system using OLE DB connection. As a test case, Arc-GIS; a commercially available GIS software in the market is integrated with the utility adjustment tracking system. Other GIS-based systems can also be integrated with utility tracking system by making subtle changes to the following method. To establish an OLE DB connection between Utility adjustment tracking system and Arc-GIS following steps have to followed in the same order: (1) Start Arc-Catalog and add the OLE DB Connection command as a button to a toolbar in Arc Catalog; (2) Click Customize on the main menu and click Customize mode; (3) The Customize dialog box opens (shown in Figure 5-1), click the Commands tab;

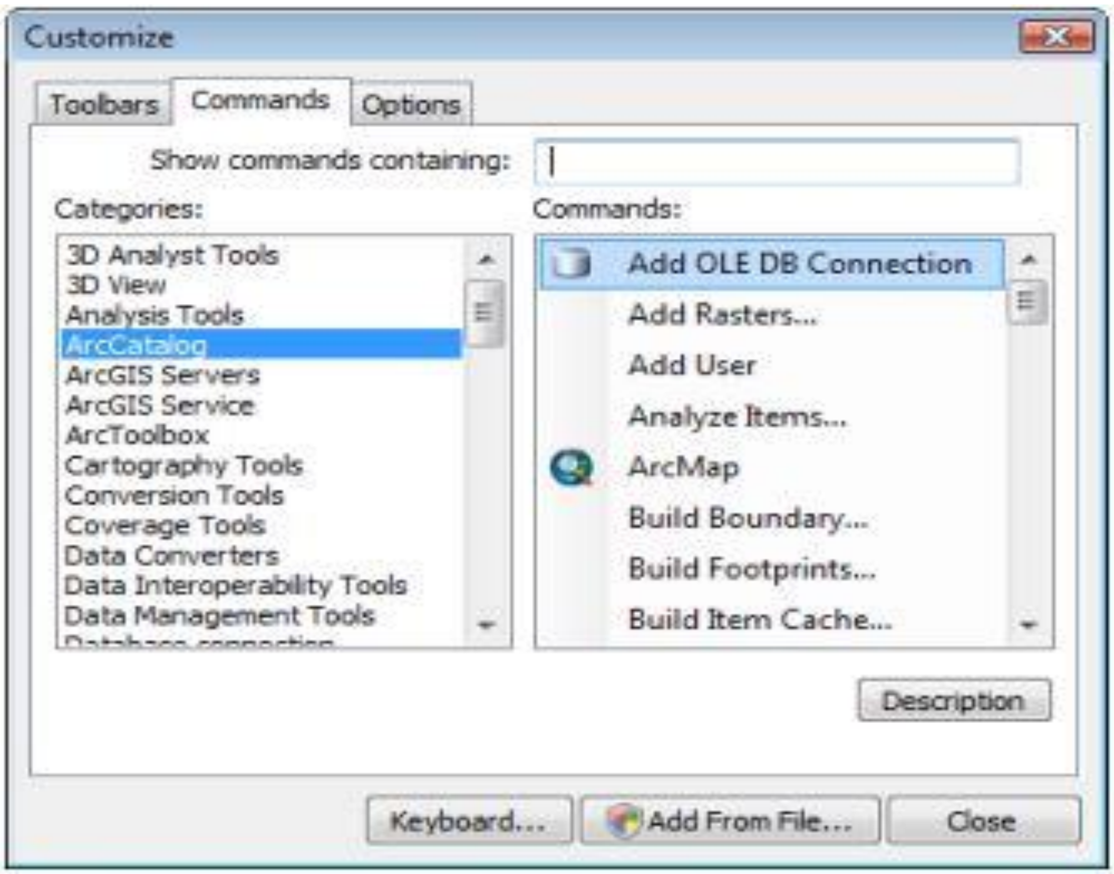


Figure 5-1: Customize dialogue box

(5) Choose Arc Catalog from the Categories list; (5) Drag Add OLE DB Connection from the Commands list onto a toolbar in Arc Catalog, the Add OLE

DB Connection button is added to the toolbar and close the Customize window; (6) Click the Add OLE DB Connection button and when the Data Link Properties dialog box appears (shown in Figure 5-2); select the Provider tab and select Microsoft Jet 4.0 OLE DB Provider; (7) Click Next on the data link properties tab and on the Connection tab, specify the database or browse to it in section one (shown in Figure 5-3).

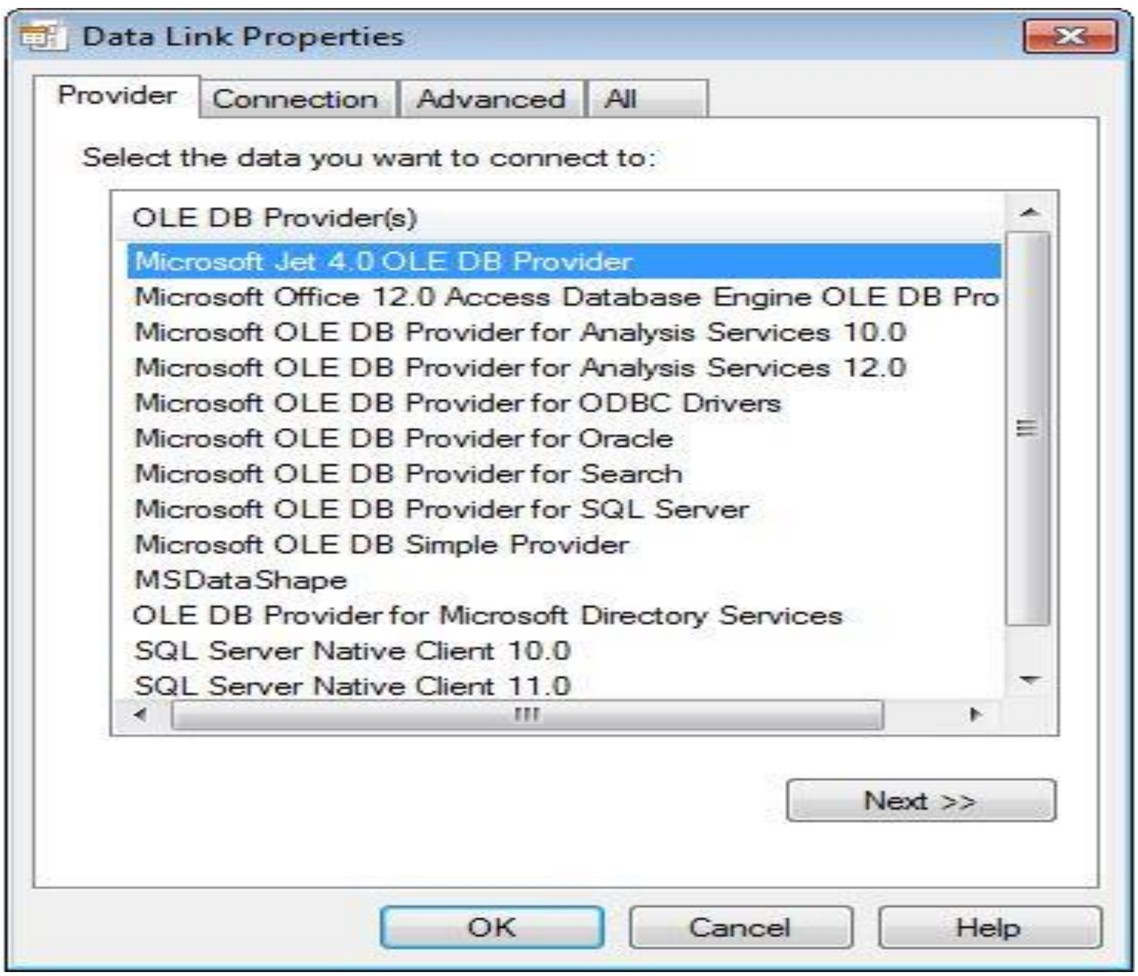


Figure 5-2: Data Link Properties Provider Window

(1) Click Test Connection to verify that you can connect to the database and Click OK if the connection test was successful; (9) To use the Access table, browse to the table through the OLE DB connection and add it to ArcMap.

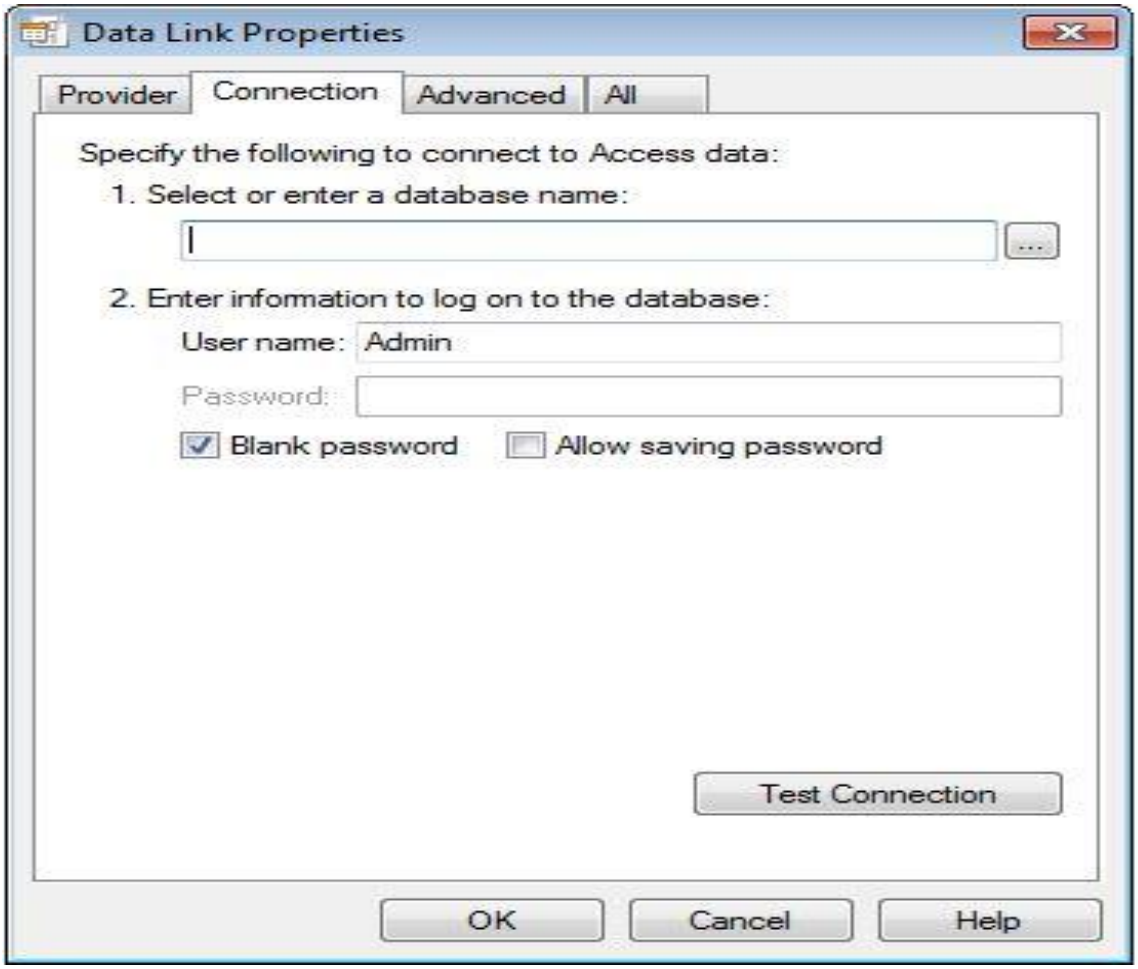


Figure 5-3: Data Link Properties Connection Window

There were many linked tables which were not viewable in the Arc-GIS environment but were present in utility adjustment tool even after establishing an OLE DB connection; this was due to an inherent interoperability issue between MS Access and

Arc-GIS. To overcome the interoperability issue, the research team developed new queries using linked tables as references so that the Arc-GIS can access these table data.

Figure 5-4 shows the overview of the integration between MS access based Utility Adjustment Tracking Tool and Arc-GIS.

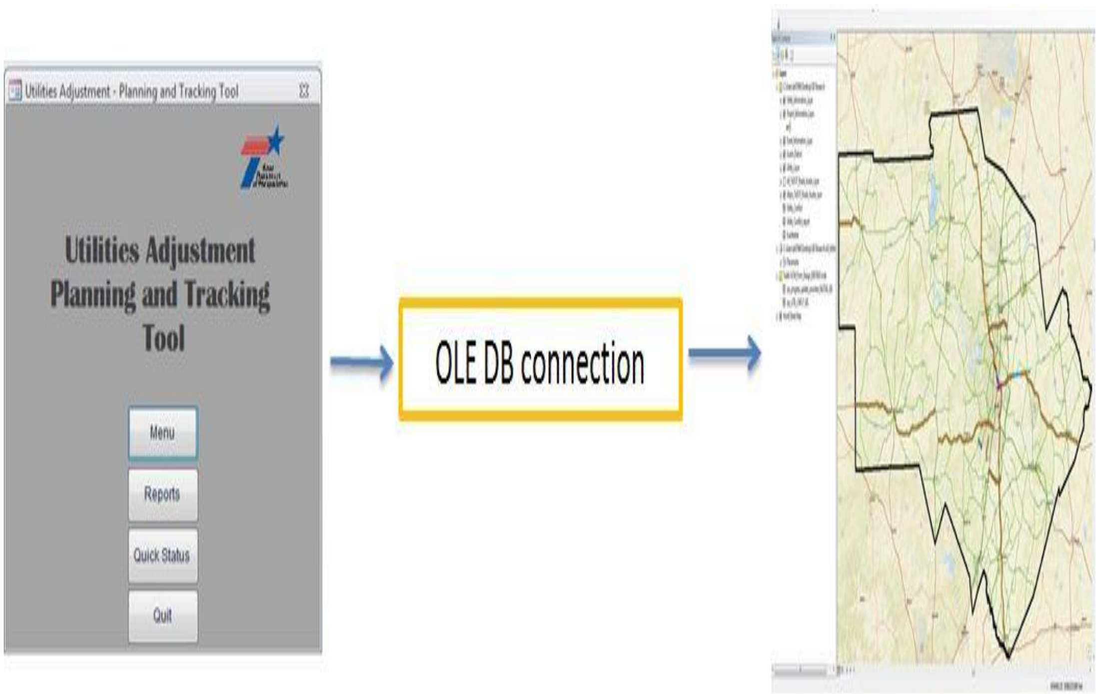


Figure 5-4: Overview of Integration between Utility Tool and Arc-GIS

SPATIAL DATA COLLECTION AND DEVELOPMENT OF SHAPEFILES

Global information systems software need spatial data to capture geographical locational information for utilities. The research team used two methods for collecting spatial data: (1) Using Trimble R10 GNSS system; (2) Using Google Earth Pro software system. The data from these two systems was used to develop shapefiles. A shapefile is a vector data storage format for storing the location, shape, and attributes of geographic features. These shapefiles are developed independent of any particular GIS platform and thus can be used with any GIS-based software. Both the methods stated above have their benefits and limitations and hence both methods were used to offset the limitations of each method. The spatial data collected using R10 GNSS system is accurate up to a thousandth of feet but at the same time requires a very expensive Trimble GPS system. The approximate cost of a Trimble R10 GNSS system can be anywhere between $25,000 and $ 30,000, and training should be provided to the person on using the Trimble R10 system before they can collect the spatial data. The Google Earth Pro software is free open source software which can be easily downloaded from the internet and is very easy to use, but the spatial data accuracy can only be up to 1 feet.

The spatial data obtained from both the methods is in the geographical X-Y coordinate system, but different file extensions, and hence different methods are used to convert this data into shapefiles. The data obtained from R10 GNSS system is in .csv or .gpx file extensions whereas spatial data obtained from Google Earth Pro is in .kmz or .kml file format.

Spatial Data Collection Using Trimble R10 GNSS System

The Trimble R10 GNSS system incorporates a GNSS antenna, receiver, internal radio, battery in a rugged light-weight unit and a Trimble TSC3 data collector. LEDs enable you to monitor satellite tracking, radio reception, data logging status, Wi-Fi status and power. Bluetooth wireless technology provides cable-free communications between the receiver and controller. The receiver can record GNSS data to the receiver's internal memory and download to a computer or USB flash drive. The receiver has no front panel controls for changing settings. To configure the receiver, the web interface which is available by connecting to the receiver's Wi-Fi via a PC or a smartphone is used (Trimble 2016). The Figure 5-5 shows the R10 GNSS with TSC3 data collector.

The working of R10 GNSS system and detailing the complete process of data collection is outside the scope of this research. The working of these systems was understood by undertaking periodic internships with utility companies who has expertise in the use of this equipment. A brief overview of data collection process and equipment set up is given below.

Figure 5-5: R10 GNSS System with TSC3 Data Collector

The R10 GNSS system is very accurate and hence great care should be taken in setting up the equipment and data collection. The research team followed these basic guidelines when collecting data with the R10 system: (1) Always place the GNSS antenna in a location that has a clear line of sight to the sky in all directions and do not place the antenna near vertical obstructions such as buildings, deep cuttings, site vehicles, towers etc.; (2) Always place the GNSS and radio antennas as high as possible. This minimizes multipath from the surrounding area and enables the radio to broadcast to the maximum distance; (3) Make sure that the GNSS receiver does not lose power always have a backup power source; (4) Never locate a GNSS receiver and antenna within 1300 feet (400 meters) of a powerful radar, communication tower, another transmitter or other GNSS antenna; (5) Avoid setting up the station directly beneath or close to an overhead power lines or electrical generation facilities, the electromagnetic fields associated with these utilities can interfere with GNSS receiver operation. Always place the R10 system in a protected and secure location and keep the system dry as much as possible.

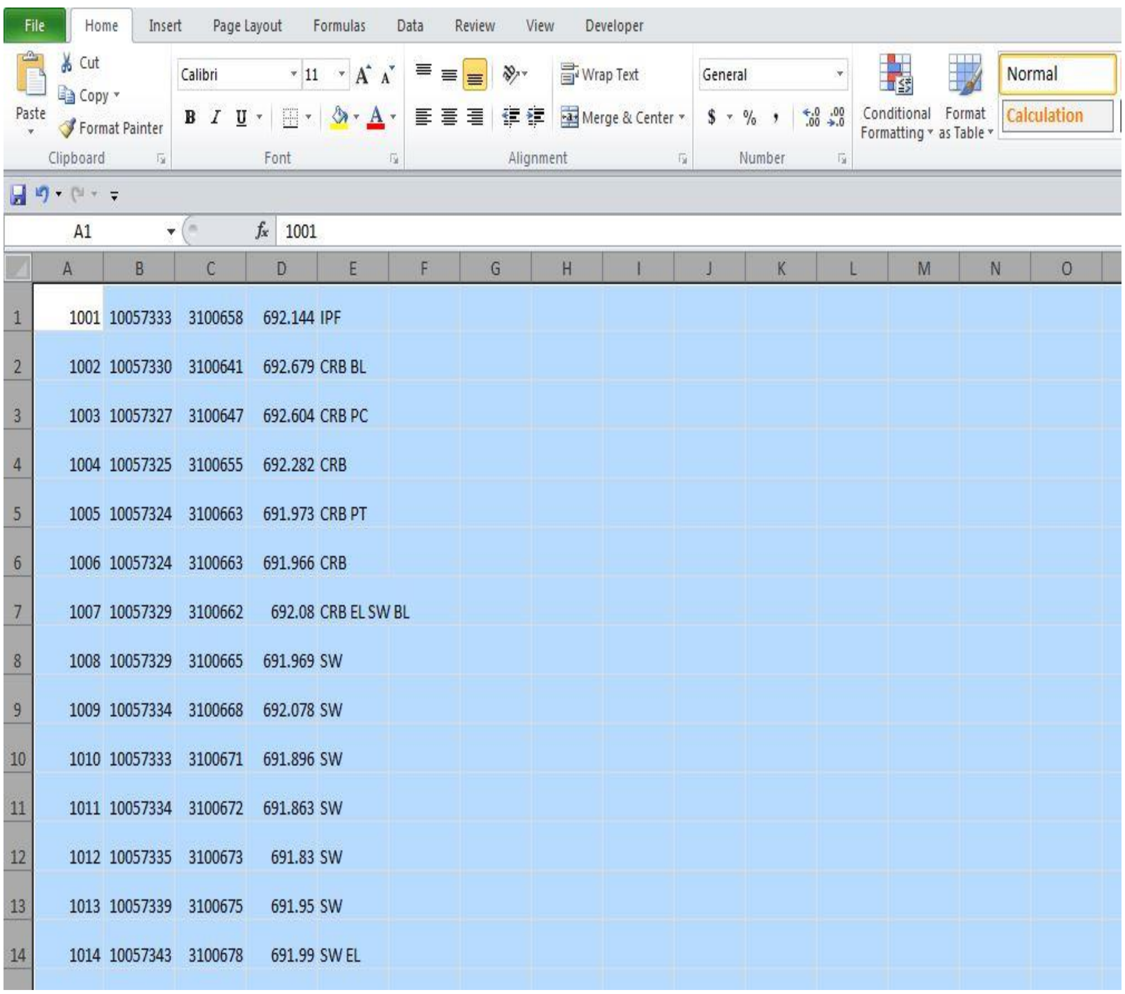
It is recommended that we set up our system on a tripod and tribrach setup. This method is the simplest, accurate and fastest method of setting up our system for collecting data. The Research team followed the following steps for data collection: (1) Always use GNSS planning software to identify the daily best and worst satellite coverage times for your location and then choose measurement times that coincide with optimal GNSS performance; (2) Clearly mark the area on a map where you want to collect data; (3) Set Up a new general survey project in TSC3 and name the project according to the street name or area; keep the data collection method as survey point data collection method and start the data collection process by staking out all the points that are required; (4) When a point is staked out make sure that the center of tripod set up on top of the point, the TSC clearly shows that the connectivity is good and the GNSS system has connectivity with more than five satellites; better satellite connectivity provides more accurate data; (5) After collecting the spatial data for all the points, save the project and shut down the R10 GNSS system; (6) Disassemble the GNSS system and safely store it in the system protective box.

Developing Shapefiles Using Spatial Data from R10 GNSS System

The spatial data collected by R10 GNSS system can be downloaded as .csv files or .gpx files. Most of the GIS software available have an inbuilt functionality to convert both these file types containing geographical X-Y locational coordinates into shapefiles. A shapefile is stored in a set of related files and contains one feature class. The .gpx files can be converted into shapefiles by using "interoperability" tools in GIS platforms. This "interoperability" tool is not included in the standard GIS packages for most of the commercially available GIS software and has to be purchased at an additional cost; due to this reason this method was not used for shapefile development. The data was downloaded from the R10 system in the form of .csv files and the "display x-y data" functionality of GIS was used to develop shapefiles.

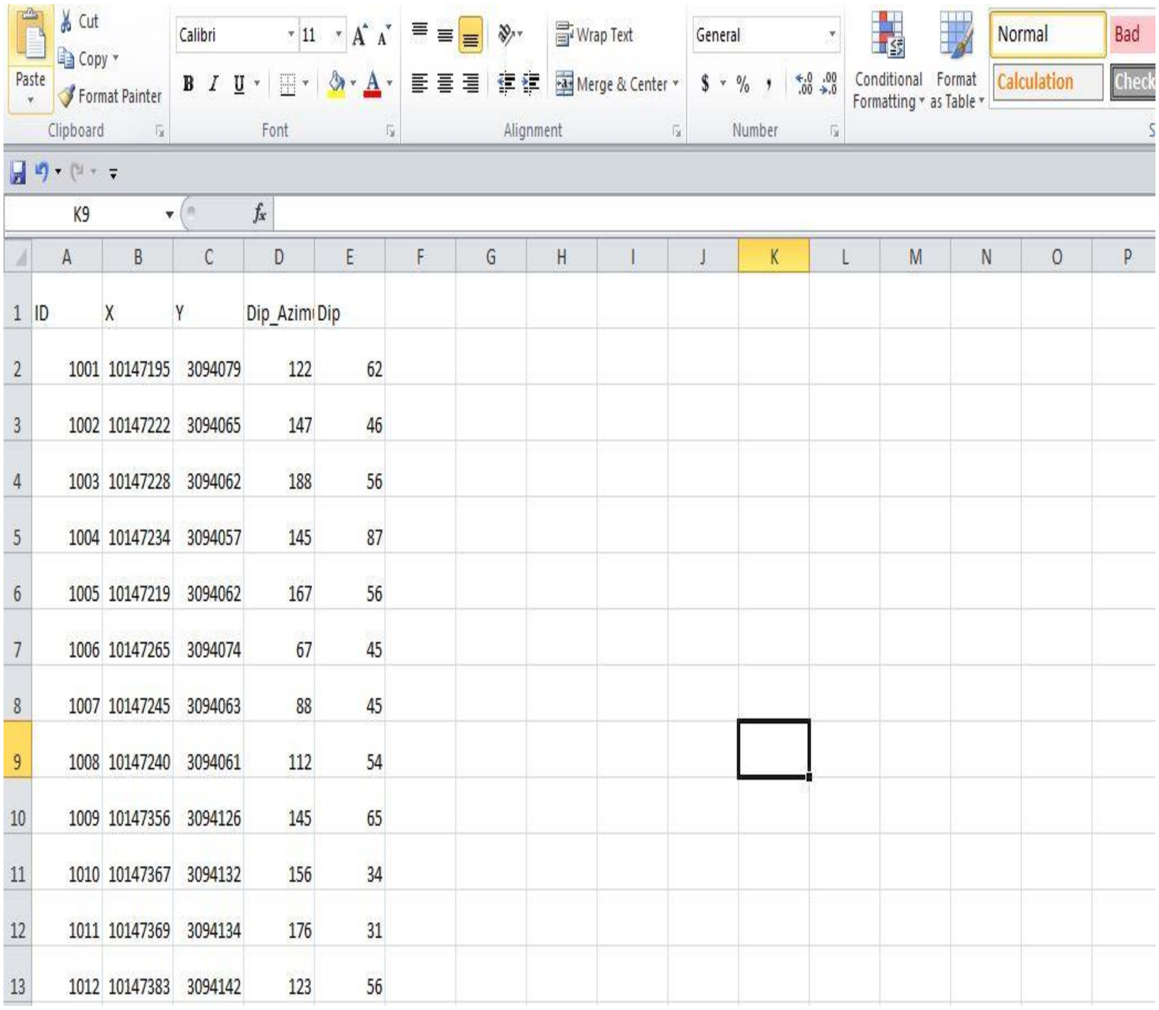
The geographical X-Y spatial data from the R10 system was downloaded in the form of .csv files, and Figure 5-6 shows the spatial data collected and downloaded in the form of the .csv file. The .csv file has raw data and cannot be directly used by GIS software for developing shapefiles. Data cleansing and data processing operations were done to convert this raw data into GIS usable data. A standardized Excel sheet was developed which converted this raw data into machine understandable language. Figure 5-7 shows the standardized Excel sheet developed. This excel sheet simply imports .csv data from R10 GPS system and converts it into GIS understandable spatial data.

The data in the .csv file contains point numbers and description of the points which the GIS system does not understand; and to convert the X-Y coordinates into shapefiles, point ID, dip, dip-Azimuth, etc. are needed. The standardized Excel sheet calculates all these attributes when the data is entered in this standardized excel sheet. The processed data is then used by the GIS software to convert the spatial data from the R10 system into shapefiles. GIS use these shapefiles to display the data on Map; where GIS datasets for our study area are displayed, explored and assigned symbols.



	A	B	C	D	E
1	1001	10057333	3100658	692.144	IPF
2	1002	10057330	3100641	692.679	CRB BL
3	1003	10057327	3100647	692.604	CRB PC
4	1004	10057325	3100655	692.282	CRB
5	1005	10057324	3100663	691.973	CRB PT
6	1006	10057324	3100663	691.966	CRB
7	1007	10057329	3100662	692.08	CRB EL SW BL
8	1008	10057329	3100665	691.969	SW
9	1009	10057334	3100668	692.078	SW
10	1010	10057333	3100671	691.896	SW
11	1011	10057334	3100672	691.863	SW
12	1012	10057335	3100673	691.83	SW
13	1013	10057339	3100675	691.95	SW
14	1014	10057343	3100678	691.99	SW EL

Figure 5-6: Raw Spatial Data in .csv File Downloaded from R10 System



	ID	X	Y	Dip_Azim	Dip
2	1001	10147195	3094079	122	62
3	1002	10147222	3094065	147	46
4	1003	10147228	3094062	188	56
5	1004	10147234	3094057	145	87
6	1005	10147219	3094062	167	56
7	1006	10147265	3094074	67	45
8	1007	10147245	3094063	88	45
9	1008	10147240	3094061	112	54
10	1009	10147356	3094126	145	65
11	1010	10147367	3094132	156	34
12	1011	10147369	3094134	176	31
13	1012	10147383	3094142	123	56

Figure 5-7: The Standardized Excel Sheet for Data Processing

The methodology described above is independent of the GIS software used, any GIS software available in the market can be used to develop shapefiles using the above methodology. As a test case, Arc-GIS was used to develop shapefiles using the above methodology. The steps in developing shapefiles using Arc-GIS have been briefly described below.

The standardized excel sheet is added to the Arc-Map environment by pressing the "add data" button on the top line of the toolbar. The excel sheet can then be viewed in the table of contents on the left side of the Arc-Map environment. Right click on the Excel sheet and select “Display XY Data” from the drop-down menu; the “Display XY Data” window is shown in Figure 5-8. The X Field and Y Field in the window are the x and y fields in the standardized excel sheet. After entering the required information in the window press ok; a shapefile is created that displays all the points in the form of a line in the Arc-map environment.

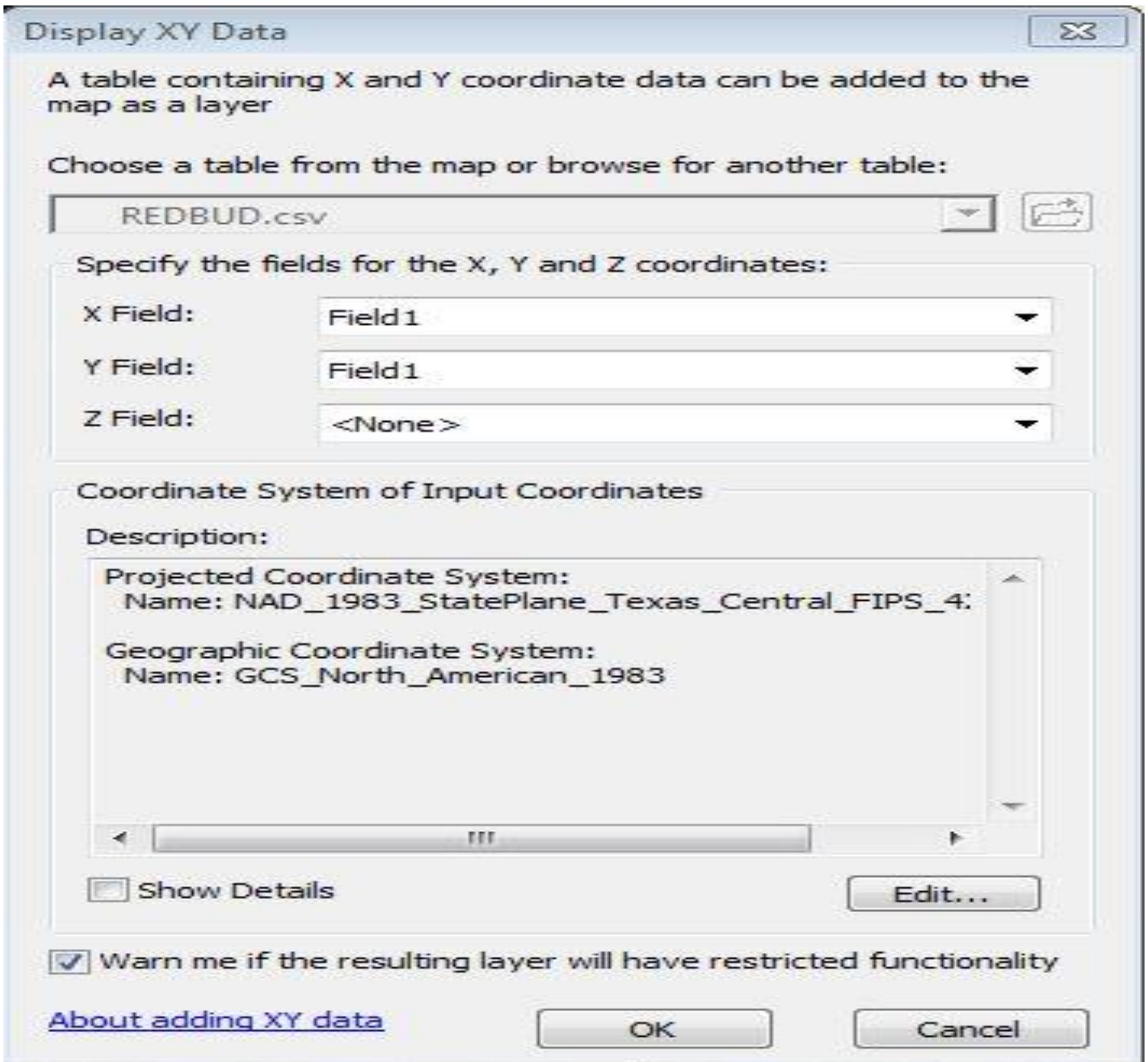


Figure 5-8: “Display XY Data” Property Window

All the shapefiles developed using the spatial data from R10 GNSS are merged into one single shapefile. The shapefiles were merged into one single consolidated shapefile so that the process of color coding and annotating these shapefiles can be easy. Each shapefile represented a utility which needed to be relocated; these were merged with other shapefiles developed using Google Earth Pro software. A total of four shapefiles were developed and merged using R10 GNSS system. Figure 5-9 shows the process of developing shapefile from the R10 spatial data using Arc-GIS.

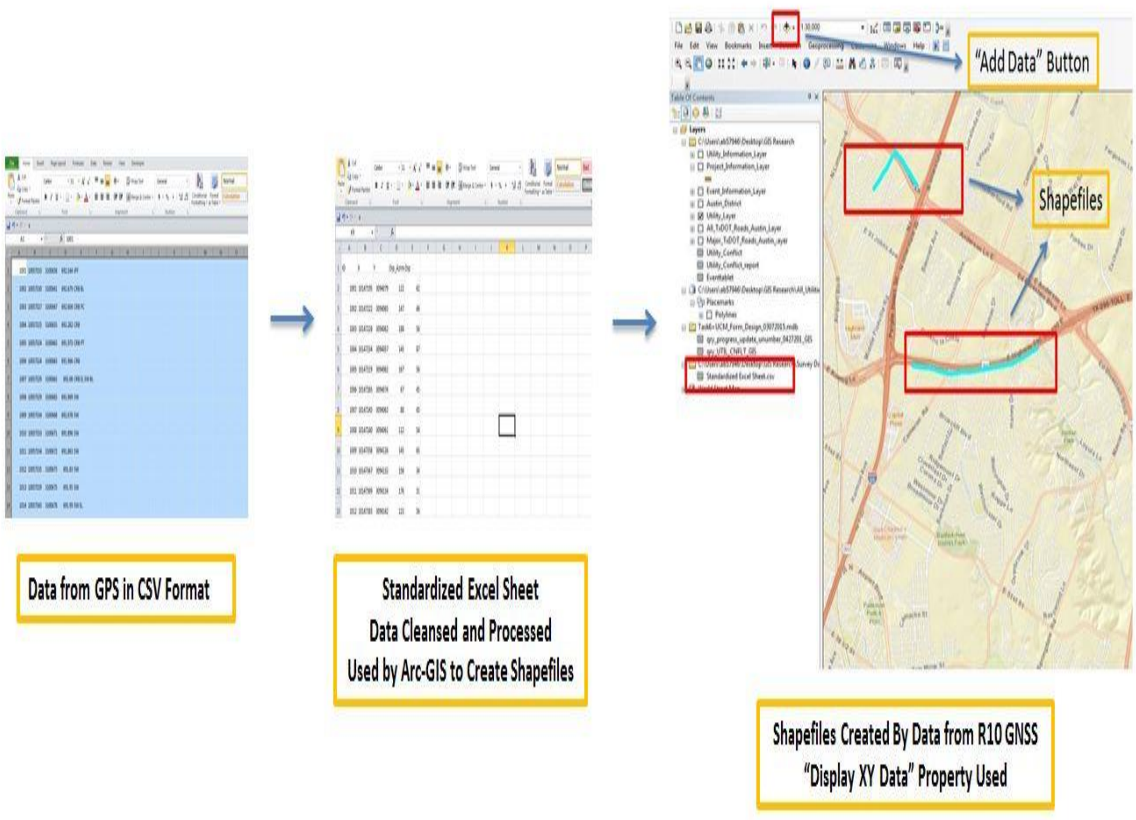


Figure 5-9: Process of Developing Shapefile Using Spatial Data from R10

Developing Shapefiles Using Google Earth Pro

Google Earth Pro is open source software that is easily available and can be downloaded for free. The software can be downloaded for free from this website (https://www.google.com/earth/). It is used for viewing satellite imagery, maps and terrain or simply putting it displays geographical spatial data in an Earth browser similar to Google maps. The data is stored in the form of a KML or a KMZ files. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard. All tags are case-sensitive and must appear exactly as they are listed in the KML reference. The Reference indicates which tags are optional and within a given element, tags must appear in the order shown in the reference.

Although R10 GNSS system provides highly accurate spatial data; the cost and skill required to use it is very high. To overcome this issue, an alternate method to develop shapefiles was also needed. After carefully analyzing several options, the research team finalized google earth pro software. The advantage of using google earth pro is as follow: (1) Free software and easily available online; (2) Very easy to use; (3) With field inputs utilities can easily be marked on a map; (4) The KMZ developed can easily be converted into GIS shapefiles.

The process of developing shapefiles using Google Earth Pro begins with a field inspection of the area where utility is located. Since the utilities needed to be marked on a map in the office; it was important to understand where these utilities were in respect to other important geographical features in the area. Considerable effort and time were spent on investigating the geographical site of the utility and tagging important markers which will help in pinpointing the exact locations of various geographical features. All this effort was necessary for developing accurate shapefiles. The next step was to develop the

KMZ file in Google Earth Pro using the above information and then using the GIS to develop shapefiles. Figure 5-10 shows the Google Earth Pro software main window.

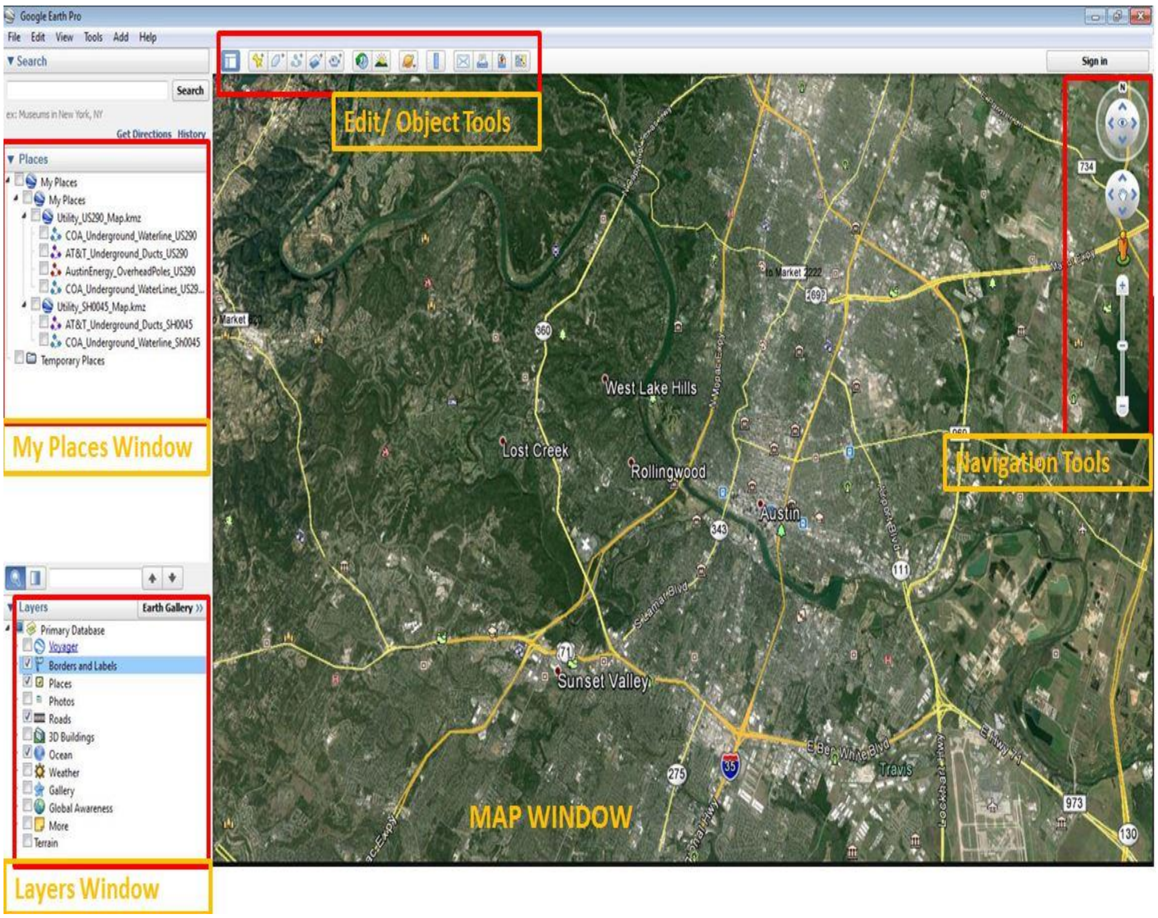


Figure 5-10: Google Earth Pro Main Window

In Edit/ Object Tools on top of the main window “Add Path” tool is used to mark the points we want to locate in the map window. After finding the area in the map window and zooming the map to an acceptable extent the points that are needed are marked by first clicking the “Add Path” tool and then clicking on the point location in the map window. The software provides us an additional feature called Street view; similar to Google maps where we can see the area in 3-D. This helped to confirm that we are in fact marking at the right point. All the points required are marked; the points marked are automatically joined by a straight line. On the top left of the main window screen; under “My Places Window” this straight line is displayed as Path1. The following naming convention for naming these utility location paths was used; UTILITY-COMPANY-NAME_UTILITY-TYPE_HIGHWAY-NUMBER. Multiple paths can be added and stored in a single KMZ file. The KMZ file is then saved and named after the area where the utilities are located. Adequate diligence should be used so that the points marked on the map and not off by more than 1 Feet. This is necessary for developing accurate shapefiles. The spatial data of these KMZ files is in geographical X-Y locational coordinates. The KMZ file is then converted into a shapefile using standard GIS built-in tool. The process of converting a KMZ file into shapefile is not very complicated, but the user should always be aware of the coordinate system used while developing the KMZ file and projection system while converting the KMZ file into shapefile.

The spatial data coordinate system depends on the type of the GPS equipment or software system being used. In our case, both R10 GNSS system and Google Earth Pro use “WGS Coordinate system.” The Other shapefiles like TxDOT roads, TxDOT highways, TxDOT projects; used during the research were all in “NAD 1983 (2011) US Feet”; while developing utility location shapefiles in GIS, the spatial data should be projected in “NAD 1983 (2011) US Feet”. Table 5-1 shows the shapefiles used in our GIS visualization system and the origin of the shapefiles.

NAME OF SHAPEFILE	ORIGIN OF SHAPEFILE
TxDOT_Roads	TxDOT Website
Utility_Shapefile	Developed Using Data from R10 GNSS/ Google Earth Pro
Austin_District	City of Austin Website

Table 5-1: Table Showing Shapefiles Used in Visualization System

Any available GIS software can be used to convert the KMZ files into shapefiles using the above methodology. As a test case, Arc-GIS was used to convert the KMZ developed using Google Earth Pro into shapefiles. To convert a KMZ file into shapefile go to the Arc Toolbox on top of the Arc-Map main window, then click the Arc Toolbox as shown in Figure 5-11. In Arc Toolbox window expand the Conversion Tool window and then click on the "KML to Layer" tool. A new window called KML to Layer will open; in the window where it is marked "input KML file" enter KMZ file name and in "output location" tab browse to the main folder where all data is stored. Click OK to create the shapefile. Figure 5-11 shows the Arc-Toolbox and the "KML to Layer" Conversion tool.

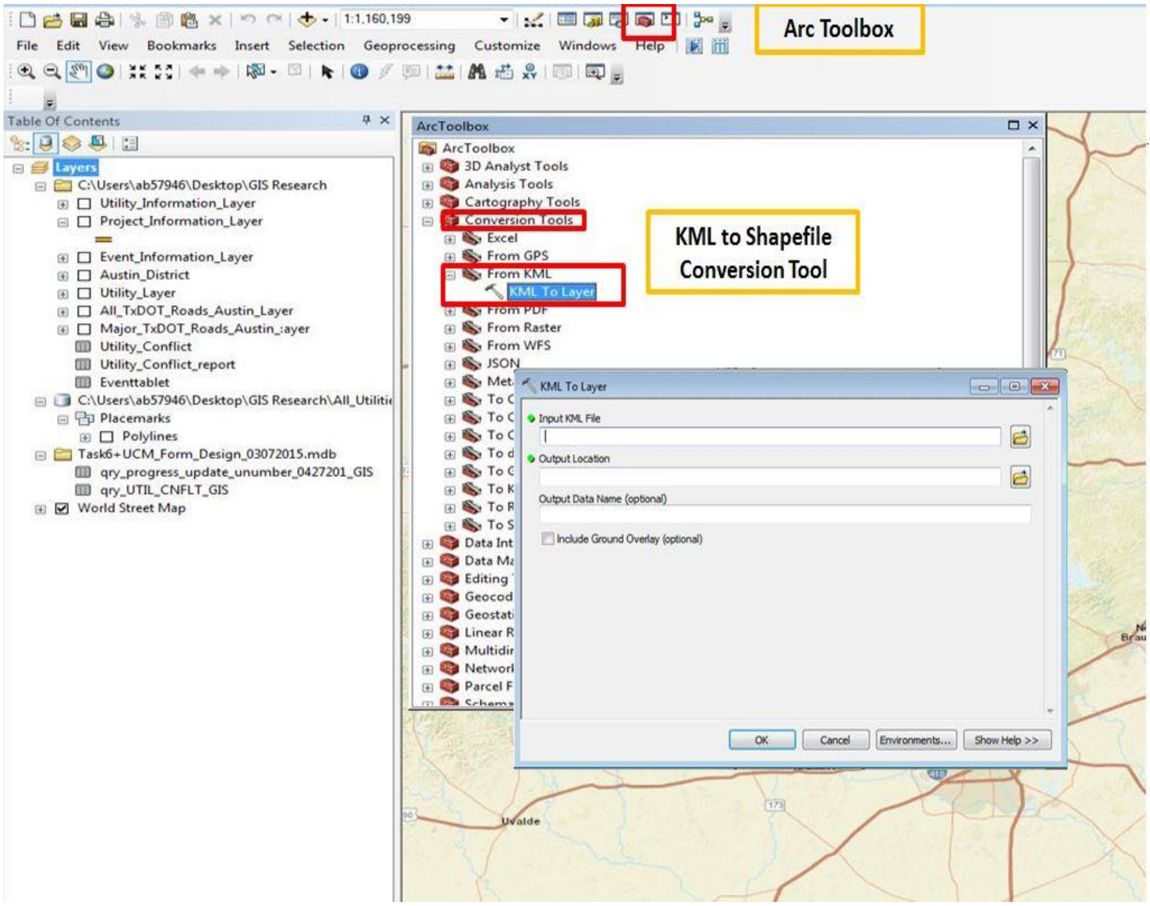


Figure 5-11: Arc-Toolbox, KML to Layer Conversion Tool

Chapter 6 Construct the GIS Visualization System

Constructing the GIS-based visualization system is the next step after integrating Utility Adjustment Tracking System and GIS. Queries are created for spatial analysis of the data and linked to GIS. These query tables are added to GIS system and joined with utility spatial data as per requirement of the system. The data in the shapefiles is processed, and these shapefiles are clipped to form layers that have the required data. To organize data in these new layers; joins and relates are created. A base map to be used for the system is determined, and layers are organized according to their use. Layers and attributes are annotated and then color coded. Finally, the customized reports are developed as per user requirements. The GIS visualization system is developed in two steps: (1) Back-end of the system; (2) Front-end of the system. Chapter 6 details the development of GIS visualization system

BACK-END OF THE SYSTEM

The development of Back-end of the system involves four different tasks: (1) Develop new queries in utility adjustment tracking system; (2) Develop new layers from shapefiles; (3) Create joins/relates to organizing data in these new layers; (4) Visual Basic and Python coding for controlling display options.

Figure 6-1 displays the process flow in the development of the GIS visualization system. The Utility Adjustment Planning Tool has already been discussed in Chapter 4. To integrate utility data in the utility tool with spatial data of utilities in visualization tool, GIS queries are created in the utility adjustment planning tool. These query tables are then imported into the GIS system.

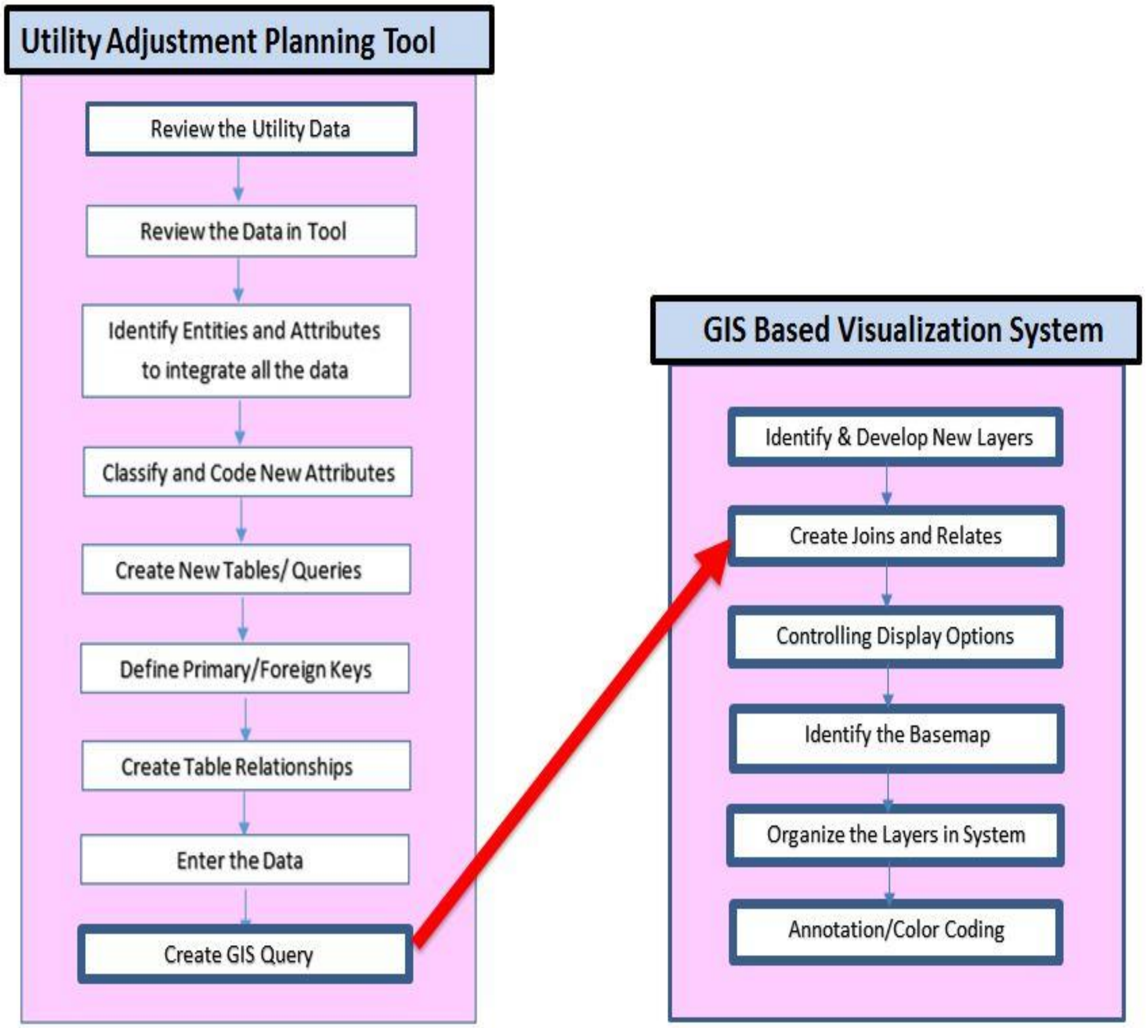


Figure 6-1: Process Flow for the Development of The Visualization system

Creating GIS Queries in Utility Adjustment Tracking System

The visualization system has to display two types of information; utility related information and project related information. The spatial information for utilities and projects was already present in the GIS as shapefiles; the Utility_Shapefile developed in Chapter 5 has spatial information on utilities and TxDOT_Roads shapefile imported from the TxDOT website has spatial information on all the roads in Texas under TxDOT jurisdiction. The Utility Adjustment Tracking system has the information relating to utility facility like the type of utility, utility size, utility company name, utility conflict type, agreement number, U-number, etc. Similarly, tracking tool also has information on projects like project CSJ number, ROW CSJ number, Project County, project manager on the project, utility coordinator on a project, etc. The spatial information for utilities and projects had to be integrated with information in utility adjustment tool so that the visualization system can display all the required information to the utility coordinators on interactive maps.

Two main GIS queries were created to integrate the utility information and project information present in GIS and utility adjustment tool. The first Query named qry_UTIL_CNFLT_GIS integrates the spatial data from utility_shapefile created in Chapter 5 with other utility related information in utility adjustment tracking tool. The U-Number was the primary key/ foreign key for this query table. The other query qry_PROJECT_INFORMATION_GIS integrates the spatial data from TxDOT_Roads shapefile imported from TxDOT website with the project related information in utility adjustment tracking tool. The Highway Number (HWY_NUM) was the primary/ foreign key for this query table. These query tables are then imported into the GIS system so that spatial analysis if any can be performed on the data.

The spatial data present in TxDOT_Roads shapefile had to be processed so that it could be integrated with our data in the utility adjustment tool. For each highway number in our utility tool, there were multiple instances of the same highway number in TxDOT_Roads shapefile; this was due to the naming convention adopted by TxDOT which is not similar to what we have used in our database. After processing the data and changing the naming convention for the highway number in TxDOT _Roads shapefile it was easy to develop the GIS query.

Developing New Layers from Existing Shapefiles

The GIS visualization system uses five major layers that have been developed using the three shapefiles shown in Table 5-1. There are three other layers that were developed to bridge the gap between the final layers that are used by the visualization system and the shapefiles. Table 6-1 shows the five major layers being used in our GIS visualization system and their base shapefiles.

In comparison to a shapefile, a layer file is just a link\reference to actual data, such as a shapefile, feature class, etc. It is not actual data because it does not store the data's attributes or geometry. A layer file primarily stores the symbology for a feature and other layer properties related to what is seen when the data is viewed in a GIS application. For example, if a layer file is sent to a user on another machine without the data it was created from, it does not display on the map because it does not contain the source data. To get the data to display properly, the user must have the layer file and the shapefile it references.

S. no	LAYER NAME	SHAPEFILE
1	Utility Information Layer	Utility_Shapefile
2	Project Information Layer	TxDOT_Roads
3	Event Information Layer	Utility_Shapefile
4	Austin District Layer	Austin_District
5	Major Project Information Layer	TxDOT_Roads

Table 6-1: Major Layers in Visualization Tool

The utility information layer is developed from the utility_shapefile. The utility_shapefile has spatial data for some utilities that are not in Austin District jurisdiction. This information was not required for the visualization tool. The shapefile is clipped by using an inbuilt functionality of GIS called “Clipping Tool”; to reflect only those utilities that are in Austin District jurisdiction. The data columns in the attribute table for this layer were also trimmed so that the user can only see the relevant information about the utilities. A bridging layer was also developed between the Utility_Shapefile and Utility Information Layer called Utility Layer; which had the same number of data columns in its attribute table as utility information layer but had spatial data of utilities which were not in Austin District jurisdiction. The main aim of this bridging layer was to have extra information in case a utility coordinator wanted to know the status of utility adjustments on critical projects just outside the Austin District which can impact the projects within the Austin District.

Project Information Layer is developed from TxDOT_Roads shapefile. The TxDOT_Roads shapefile has spatial data on all the roads that are within the jurisdiction of TxDOT. The shapefile was clipped to reflect roads in Austin District. The GIS query qry_PROJECT_INFORMATION_GIS provides the project information on all these major roads. The data columns in the attribute table for this layer were also trimmed so that the user can only see the relevant information about the projects. A supplementary layer; Major Project Information Layer which displayed project information data only on TxDOT highways that are passing through the Austin District was also created.

Event Information Layer is developed using Utility_Shapefile. The shapefile is clipped to reflect only the information that is relevant to Austin District. This layer has other joins and relates to display data on event related information for utilities. This is one of the most important layers since most of the reporting data requirements come through this layer.

Austin District Layer is developed using Austin_District shapefile which can be downloaded from District of Austin development website. The Austin_District shapefile provides spatial data on Travis County jurisdiction, Austin District jurisdiction, and City of Austin jurisdiction. The shapefile is clipped to reflect only Austin District jurisdiction. The research was primarily concerned with City Of Austin jurisdiction but still used Austin District jurisdiction to provide more flexibility to the visualization tool. This layer was the last layer to be developed, and it helps the user; utility coordinators, in this case, to focus on a particular area.

Creating Joins/Relates to Organize Data in the Layers

The layers developed in GIS visualization system are used for displaying utility information and project information. All this data is present in different tables in utility adjustment tracking tool. To display information for individual utilities or individual projects, the data needs to be queried from multiple tables and organized accordingly in each layer. This can be done by using the functionality of joins and relates in GIS environment. Through a common field, known as a key, records in one table can be associated with records in another table. Associations can be done in several ways, including by joining or relating tables temporarily in our map or by creating relationship classes in our geodatabase that maintain more permanent associations. Joins can also be based on spatial location. In the visualization tool all the joins and relates are temporary and are only valid for individual map environment.

In an attribute join, a data table is joined to a layer based on the value of a field that can be found in both tables. The name of the field does not have to be the same, but the data type must be the same; numbers are joined to numbers, strings to strings. Joins by location, or spatial join, uses spatial associations between the layers involved to append fields from one layer to another. Unlike joining tables, relating tables simply defines a relationship between two tables. The associated data isn't appended to the layer's attribute table; like, it is in a join. Instead, the related data is accessed through selected features or records in our layer or table. Relates that are added to a layer or table in a map are essentially the same as simple relationship classes defined in a geodatabase, except that they are saved with the map instead of in a geodatabase (ESRI, Joins and Relates 2016).

The Utility Information Layer uses two joins for organizing information. The Utility Information Layer is joined with T_UTIL_CNFLT and T_UTIL_FCLTY tables in Utility Adjustment Tracking Tool. The Project Information layers and Major Project Information Layer are joined to three tables from Utility Adjustment Tracking Tool; T_DOT_PROJ_SUP, DOT_USER, and DOT_OFFC. The Event Information layer has the most complicated joins and relates; The Event Information Layer is joined with T_MILESTONE and T_UTIL_CNFLT_SUP and has relates with T_EVENT and T_EVENT_ACTION. The Austin District layer has no joins and relates.

Python and Visual Basic Coding for Controlling Display Options

The GIS visualization system was developed to provide information in an aesthetically pleasing way; this was achieved by controlling the display options on our visualization system. Extensive back-end coding was done using Python and Visual Basic so that the relevant information can be displayed by clicking on the respective elements. The project information for each project is displayed when we click on that particular project in the GIS map environment. Similarly, when we click on the different utilities, we can see the conflict information for them. There are some layers which the user can select or deselect depending on the information required while some layers have been permanently barred from selecting by the user so that the underlying data is not affected in case the user does something wrong. All this was achieved by controlling the display characteristics of GIS environment.

Python is a free, cross-platform, open-source programming language that is both powerful and easy to learn. The scripting for geoprocessing in GIS is done in Python, and it provides us more opportunities to control the displaying behavior in GIS environment. Advantages of using Python are (1) Easy to learn; (2) Highly scalable, suitable for large projects; (3) Portable across multiple platforms; (4) Embeddable (making GIS scriptable); (5) Stable and mature.

FRONT-END OF THE SYSTEM

The development of user interface for the visualization system was one of the most challenging aspects of the tool development. A good user interface should be clear, concise, familiar, responsive, consistent and efficient for the user. The main issue with user interface development is that optimizing one of the characteristics might interfere with working of the others. The main challenge for the research team was to strike the perfect balance between all the characteristics of a good user interface. The development of the Front end of the system involved following five tasks: (1) Establish the base map for the visualization tool; (2) Organizing layers in the visualization tool; (3) Annotations/ color coding/ zoom extent of layers; (5) System reports. This section discusses the development of front-end of the GIS visualization system.

Establish the Basemap for the Visualization Tool

A base map provides a background of geographical context for the content displayed in the Arc-map. When a new map is created, the user can choose any base map; and can change the base map of the current map at any time by using the base map gallery or using any other layer as the base map. There are three ways of selecting a base map: (1) Selecting base map from the base map gallery; (2) Developing a personal base map; (3) Creating multilayer base map. The research team used the first method of selecting a base map.

The base map gallery includes a variety of choices like topography, imagery and street maps. The method of adding base map to our map was not a complicated one but deciding which map to choose as the system base map required an understanding of functionality and logic of different base map available in the base map gallery and the visualization characteristics of the GIS visualization system. The GIS visualization system uses World Street Map as the base map. Other street maps available in the base map gallery were analyzed, but most of them used projection system other than WGS_1984_Web_Mercator_Auxiliary_Sphere. The spatial data collected by the research team was also in the WGS_1984 projection system and the shapefiles developed from them were projected in NAD 1983 (2011) US Feet coordinate system. The research team used the World Street Map as the base map and projected it in NAD 1983 (2011) US Feet coordinate system. The two major shapefiles used in the development of the GIS visualization system use spatial data that reflects street or highway spatial data in some form, hence selecting a street base map was a natural choice for the research team.

The methodology described above is independent of the GIS software used; as a test case, ArcGIS is used to describe the process of selecting a base map. Figure 6-2 shows the base map gallery and various base maps in it. The process of selecting base map from the base map gallery is described in brief here: (1) Verify that you are signed in and if you want to save changes verify that you have privileges to create content; (2) Open the map and click the “Add Data” button and from the drop-down list select “Add Basemap”; (3) Click the thumbnail of the base map you want to use on your map and click the Add button at the bottom of the “Add Basemap” window, the base map is added to the map layer; (4) Right click on the map and in the drop down menu select properties; (5) Read the description and understand the contents of the base map; (6) Save the map to add the Basemap in the Arc-Map environment.

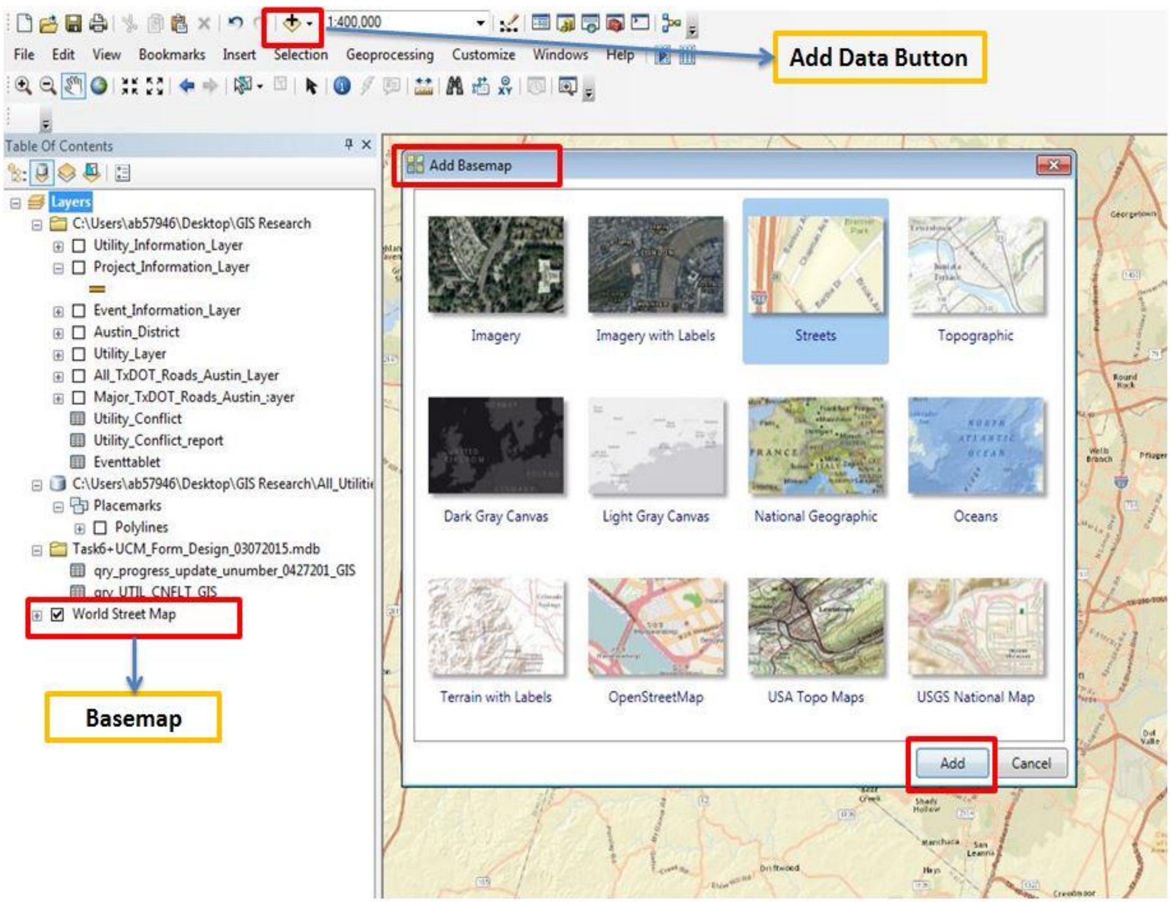


Figure 6-2: Add Basemap Gallery Window in ArcGIS

Organizing Layers in the Visualization Tool

There are five primary layers in the visualization tool that were organized according to their usage and the underlying data. There are three bridging layers in the tool that were developed as a bridge between the shapefiles and the primary layers. The details of bridging layers have been discussed in above sections. The layers are stacked on each other, the order in which the layers are displayed in the table of content is the actual order in which layers are organized. The top layer can hide the layers that are below it in the table of contents, and as a result, the user might not be able to see or select some important points on the map. It is also possible that user can see a point but is not able to select it due to the layer above it; to overcome all these issues the research team did a comprehensive testing to decide the order of the layers.

Some layers like Austin District Layer and World Street Map were made "Not Selectable." When layers are listed by selection, they are grouped into these categories: (1) Selected— the layer has features selected; (2) Selectable (no features selected)—the layer is selectable, but has no features currently selected; (3) Not Selectable—the layer is not selectable, and cannot use the interactive selection tools to select features in it. These layers do not have any utility-related or project related attribute data and provide no information on utility adjustment process; by keeping these layers "Not Selectable," the user avoids unnecessary selection of these layer attributes which in turn improves the efficiency of the visualization system.

As a test case, ArcGIS has been used to display the order of the layers in the visualization system. It is important to understand that the methodology used to develop the visualization system is independent of GIS software used. Figure 6-3 shows the order in which layers are organized in ArcGIS visualization tool.

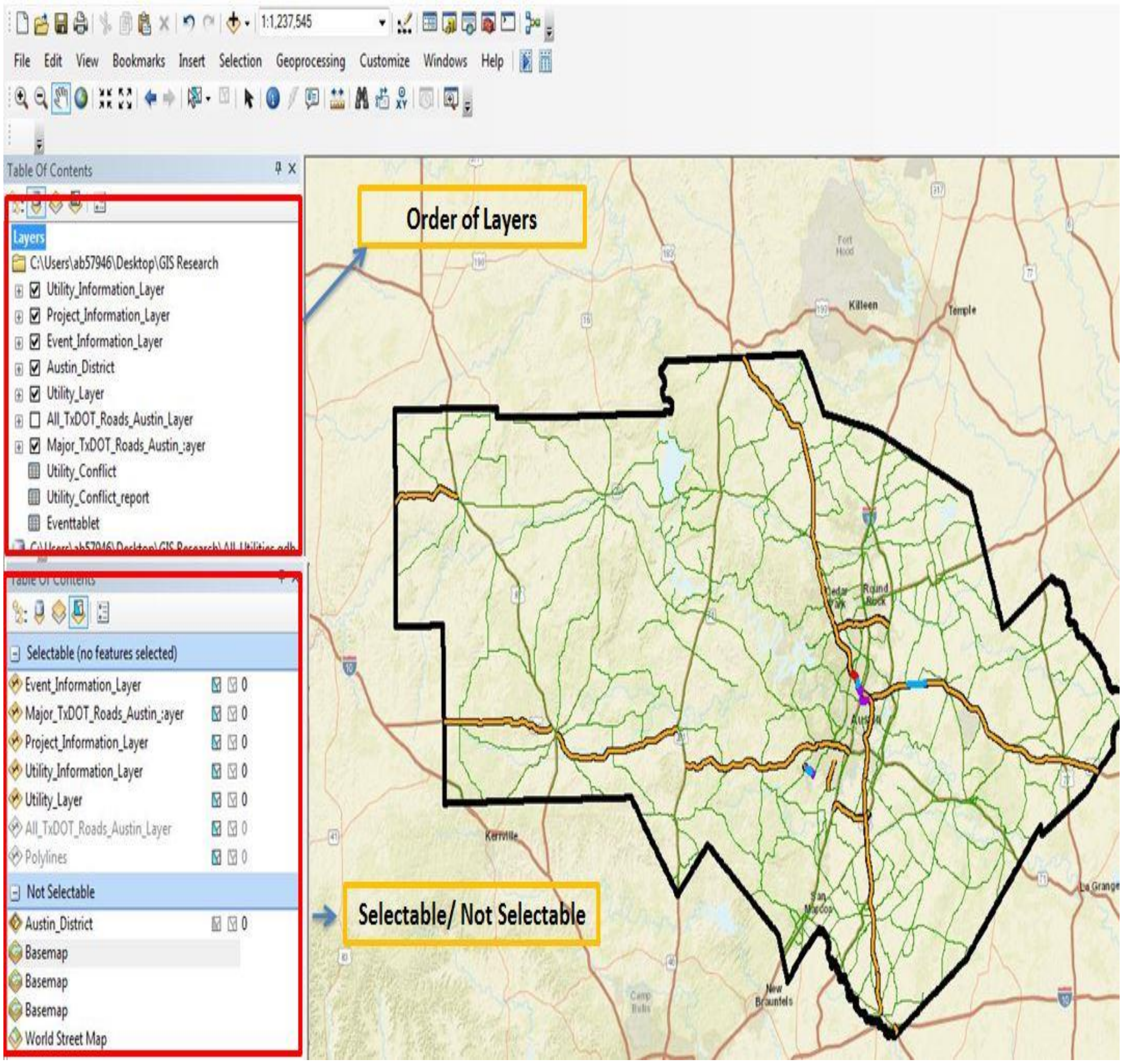


Figure 6-3: Figure showing Organization of Layers in ArcGIS

Annotations/ Color Coding/ Zoom Extent of Layers

When a data layer is added to a GIS map environment, all the data looks the same; this is because the data is set to be symbolized by only one color or symbol. All the layers in visualization tool were customized by developing symbology for different categories, controlling the display options of various layers and controlling zoom extent of each layer.

In utility information layer the three different utility types are color coded so that the utility coordinators can easily distinguish between the utility facilities types on the map. The utility facility types are color coded very logically; blue for waterlines, red for electricity/ power lines and purple for telecommunication lines. The color coding helps the utility coordinators to search for a utility facility type in a map environment easily. The highways or major roads on which these utility facilities are present are represented by orange color between two black lines; other TxDOT roads are represented as thin green lines on the map. Highways are color coded differently than other TxDOT roads so that the utility coordinators can easily distinguish which utility relocations are on priority projects. The Austin District layer is color coded as the boundary with dark black bold lines; the Austin District layer represents the jurisdiction of Austin District.

The display options for each layer are also customized so that the utility coordinators can see the relevant information of each project and utility simply by clicking on the individual project or utility. Clicking any individual project displays the highway number of the project, CSJ Number, let date for the project, ROW status, project status, utility coordinator on the project, project manager for the project and county in which the project is located. Similarly by clicking on any utility TxDOT utility coordinator can see the utility number, utility description, utility company and utility contact person information for that particular utility.

The visualization system becomes slower as more data is added to it; when a utility coordinator tries to zoom in or zoom out, it takes more time for the system to load and display the information. This issue is resolved by controlling the zoom extent of various layers. A restriction is placed on the maximum and minimum extent to which a layer can be zoomed; if the map is zoomed beyond that restriction, the layer automatically gets locked and becomes invisible. This main purpose of controlling zoom extent of layers is to improve the efficiency of our visualization system.

Figure 6-4 shows the display options and symbology for all the layers in ArcGIS map environment.

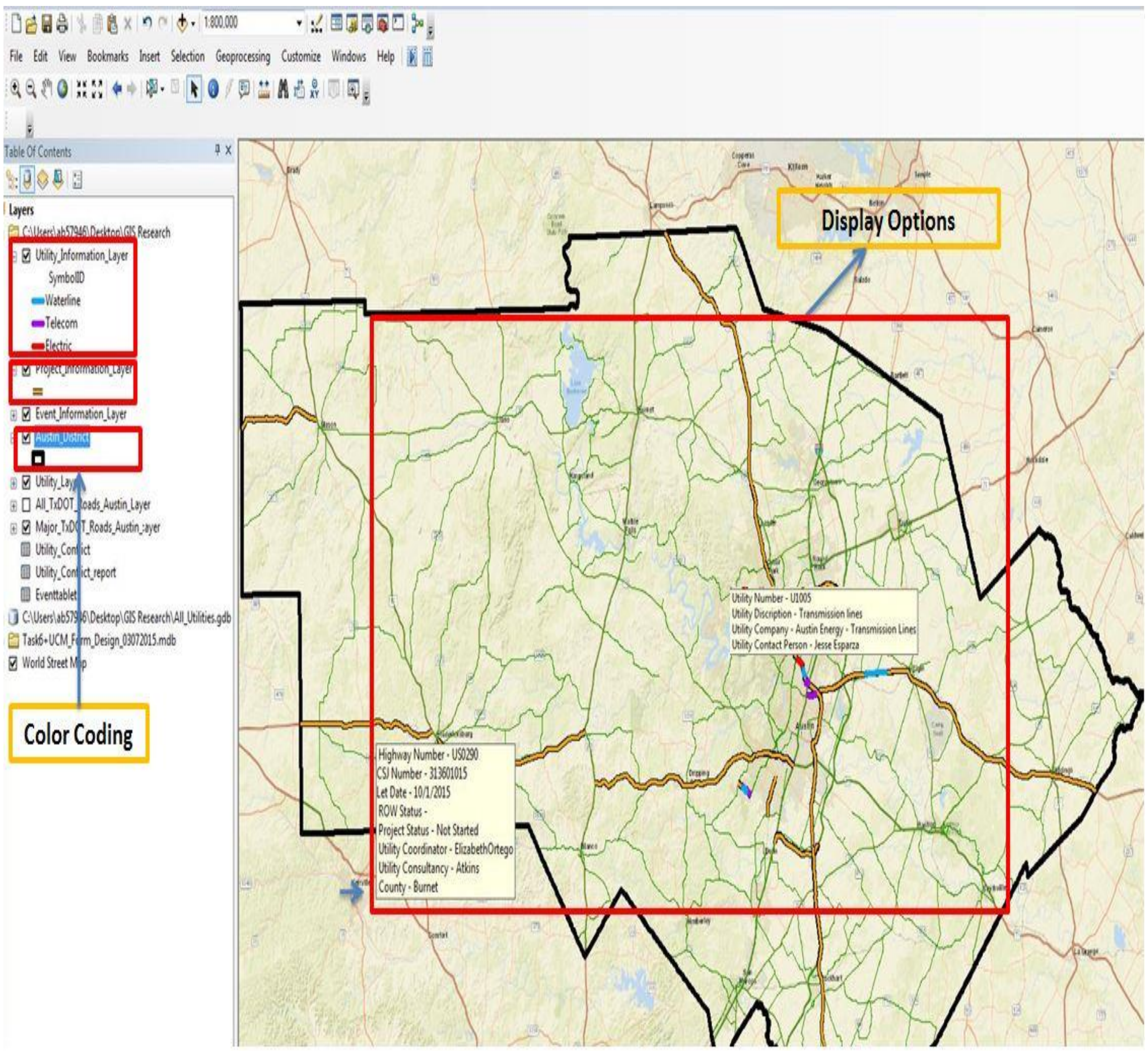


Figure 6-4: Figure showing Symbology and Display Options in ArcGIS

System Reports

A user of the system can create their reports according to their requirements or use the customized reports. There are four customized reports in the visualization system (1) Project Report; (2) Conflict Report; (3) Event Report (Project Level); (4) Status Report (U-Level).

The customized reports are developed using the Export Report function in GIS. The Export Report function provides a mechanism to automate the generation of reports using layers or tables authored in a map document or layers in a layer file. A report layout file authored in any GIS Map environment is a template that stores information about the content and placement of the items in a report. The report layout file is used along with the source data in a map document to create output reports. The source data can also have associated joins and related table information that is used within the report. The dataset options in the reporting tool were used to determine how the records are processed in each report. There are four ways of processing the records in each report: (1) All Selected; (2) Selectable; (3) Definition Query; (4) Visible Extent. The selectable method was used for processing records in the system reports.

As a test case, ArcGIS is used to explain the process of report generation. The methodology used in the development of reports in the visualization system is independent of the GIS software; any GIS software in the market can be used. Figure 6-5 shows how we can generate customized report using the Selectable method in ArcGIS. This Export Report function has a dependency on the ArcMap installation. Therefore, Export Report can only be executed on machines that have ArcMap installed. Moreover, Export Report will not work as a Geoprocessing Service. The source data must exist in a map document or layer file, and the dataset field names must match those in the report layout file for Export Report to execute properly (ESRI, ArcGIS for Desktop 2016).

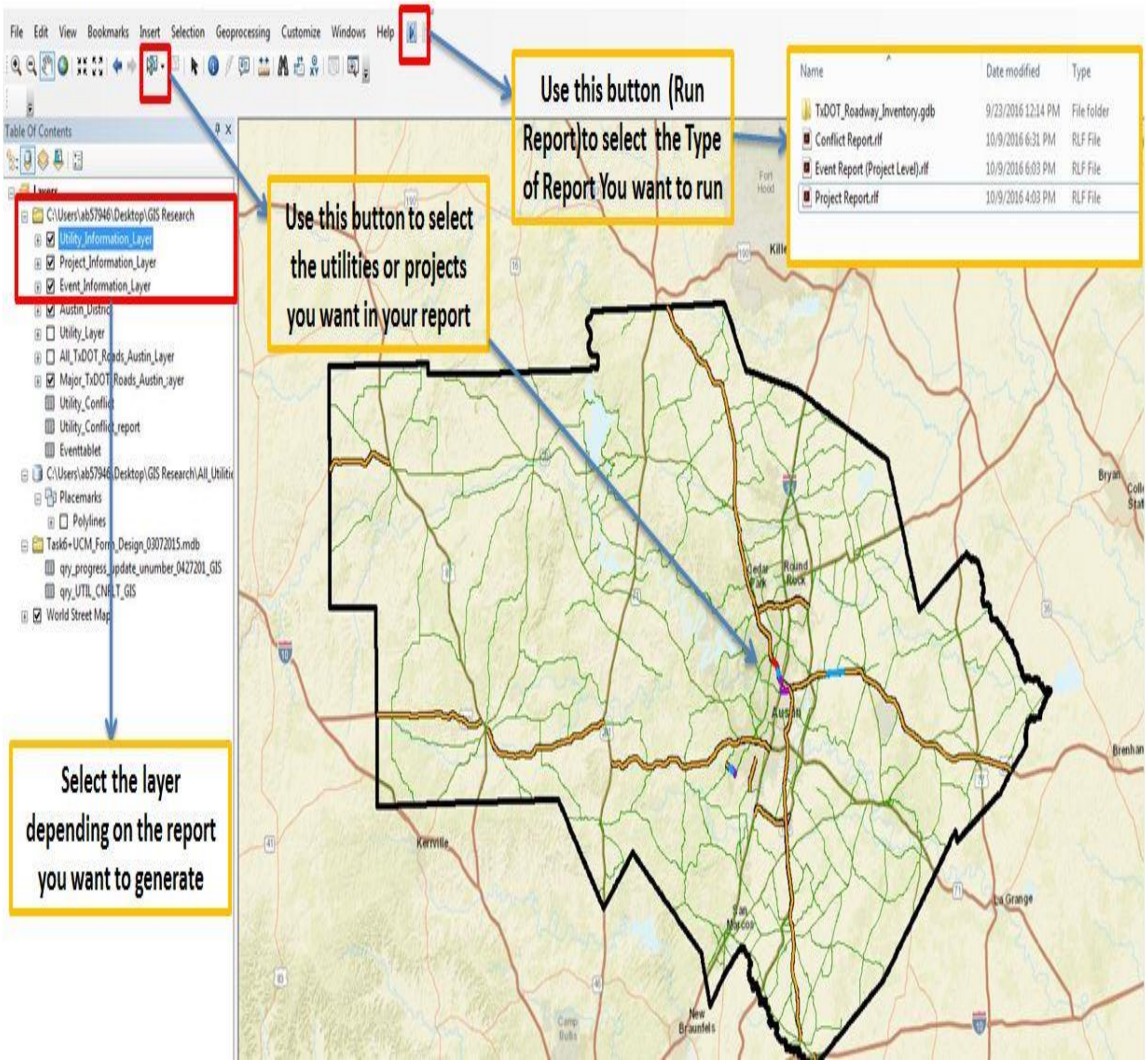


Figure 6-5: Figure Showing how to Generate a Report

The first report in the Visualization system is the Utility Conflict report. This report is parsed by the project number. The user selects the projects on which he wants information about utility conflict, and the system generates the utility conflict report. Figure 6-6 shows the utility conflict report.

Utility Conflict Report

PROJECT NUMBER

121212131

U-NUMBER	UTILITY TYPE	FACILITY DESCRIPTION	CONFLICT	COMPANY NAME
U1005	Transmission Tower	AustinEnergy_OverheadPoles_US183	-1	Austin Energy - Transmission Lines
U1006	Water	COA_UndergroundWaterlines_US183	-1	City of Austin - Water
U1007	Buried Fiber Optic	AT&T_UndergroundDucts_US183	-1	(AT&T Fiber, (Legacy T)) Osmose Communications

313601015

U-NUMBER	UTILITY TYPE	FACILITY DESCRIPTION	CONFLICT	COMPANY NAME
U1001	Water	COA_Underground_Waterline_US290	-1	City of Austin - Water
U1002	Buried Fiber Optic	AT&T_Underground_Ducts_US290	-1	(AT&T Fiber, (Legacy T)) Osmose Communications

Figure 6-6: Utility Conflict Report

The second report in the Visualization system is the Event Report (Project Level). This report is parsed by the project number. The user selects the projects using select option, and the system generates a report which displays all the events associated with all the utilities that are undergoing adjustments in that particular project. Figure 6-7 shows the Event Report (Project Level).

The third report in the Visualization system is the Status Report (U Level). This report is parsed by U Number of each utility. This report displays information on the status of individual utilities by displaying events associate with the utility adjustment process. Figure 6-8 shows the Status Report (U Level). The fourth report in our visualization system is Project Information Report and displays the project related information for all the projects that are selected.

Project Level Event Report

PROJECT NUMBER

121212131

U.NUMBER	ACTIVITY	DISCRIPTION	DATE	COMPANY NAME
U1005	Identify Utility Companies On The Project	Again Identify	<null>	Austin Energy - Transmission Lines
U1005	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	4/5/2016	Austin Energy - Transmission Lines
U1005	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	6/7/2016	Austin Energy - Transmission Lines
U1006	Identify Utility Companies On The Project	COA in conflict identified	3/23/2016	City of Austin - Water
U1006	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	4/5/2016	City of Austin - Water
U1006	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	4/13/2016	City of Austin - Water
U1007	Identify Utility Companies On The Project	AT& T in conflict Identified	8/11/2015	(AT&T Fiber, (Legacy T)) Osmose Communications
U1007	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	3/16/2016	(AT&T Fiber, (Legacy T)) Osmose Communications
U1007	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	6/14/2016	(AT&T Fiber, (Legacy T)) Osmose Communications

Figure 6-7: Event report (Project Level)

Status Report (U-Level)

U-NUMBER	ACTIVITY NAME	EVENT DISCRIPTION	EVENT TIME
U1005			
	Identify Utility Companies On The Project	Again Identify	<null>
	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	4/5/2016
	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	6/7/2016
U1006			
	Identify Utility Companies On The Project	COA in conflict identified	3/23/2016
	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	4/5/2016
	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	4/13/2016
U1007			
	Identify Utility Companies On The Project	AT& T in conflict Identified	8/11/2015
	Prepare Utility Conceptual Relocation Plan	Utility Conceptual relocation Plan developed	3/16/2016
	Provide 60% Roadway Plans For Vertical Design	60% roadway design done	6/14/2016

Figure 6-8: Status Report (U-Level)

VALIDATION

The research methodology used for developing the visualization system for tracking utilities is independent of the relational database and GIS software used. There are many relational databases available in the market like Oracle, MySQL, MicrosoftSQL, IBM DB2, and MS Access. Similarly, there are many GIS-based software like ArcGIS, QGIS, GRASS GIS, MapInfo, Global Mapper, etc. in the market. The research methodology explained in this thesis can be used to develop a visualization tool using any combination of a relational database and GIS software.

To validate this research methodology; Utility adjustment tracking system, an MS Access-based relational database and ArcGIS 10.3.1 were used. Four utility adjustment projects were selected based on their location and utility information available with us. The projects are named according to the highways they are located on (1) US0377 - 0.735 mi East of FM 1105; (3) US 0183; (4) SH 0045 – Williamson area; (4) US 290 – South of Lacrosse. Nine utility facilities were selected, and spatial data was collected for them using Trimble R10 GNSS system and Google Earth Pro as explained in the research methodology. The list of nine utilities is given in Table 6-2.

S. no	**UTILITY NAME**	**HIGHWAY NUMBER**	**UTILITY NUMBER**
1	COA UNDERGROUND WATERLINE	US 290	1001
2	AT & T UNDERGROUND DUCTS	US 290	1002
3	AUSTIN ENERGY – WOODEN OVERHEAD POLES	US 290	1003
4	COA UNDERGROUND WATERLINE	US 290	1004
5	AUSTIN ENERGY – WOODEN OVERHEAD POLES	US 183	1005
6	COA UNDERGROUND WATERLINE	US 183	1006
7	AT & T UNDERGROUND DUCTS	US 183	1007
8	AT & T UNDERGROUND DUCTS	SH 0045	1008
9	COA UNDERGROUND WATERLINE	SH 0045	1009

Table 6-2: Utility Facilities in ArcGIS Visualization System

OLE DB connection was then used to integrate Utility Adjustment and Tracking System with ArcGIS. GIS queries were developed in the utility adjustment tracking system, and the project and utility related information in utility adjustment tool were then available to ArcGIS for processing. The spatial data obtained using GPS system and Google Earth was then converted into shapefiles using “x-y conversion” tool available in ArcGIS. This spatial data in shapefiles was then linked with project and utility data using joins and relate function. A “World street map” available in the basemap window in ArcGIS was selected as a basemap for the visualization tool. Seven Layers were developed to display utility information, project information, highways, Austin District jurisdiction, etc. Annotation, color coding, and zoom extent control were done using Python and VB coding. Reports for this ArcGIS visualization system were also developed using the selectable method for report generation as explained by the research methodology.

The system was tested for different case scenarios; various geospatial queries were run, reports were generated using the geospatial data from the shapefiles and utility and project related data from utility adjustment tool. The user could click on any highway and utility displayed on arc map and get the required information. Different utilities and highways were color coded differently and could be easily found. The system worked without any errors. Figure 6-9 shows the visualization system developed using utility adjustment tracking system as a relational database and ArcGIS as GIS platform.

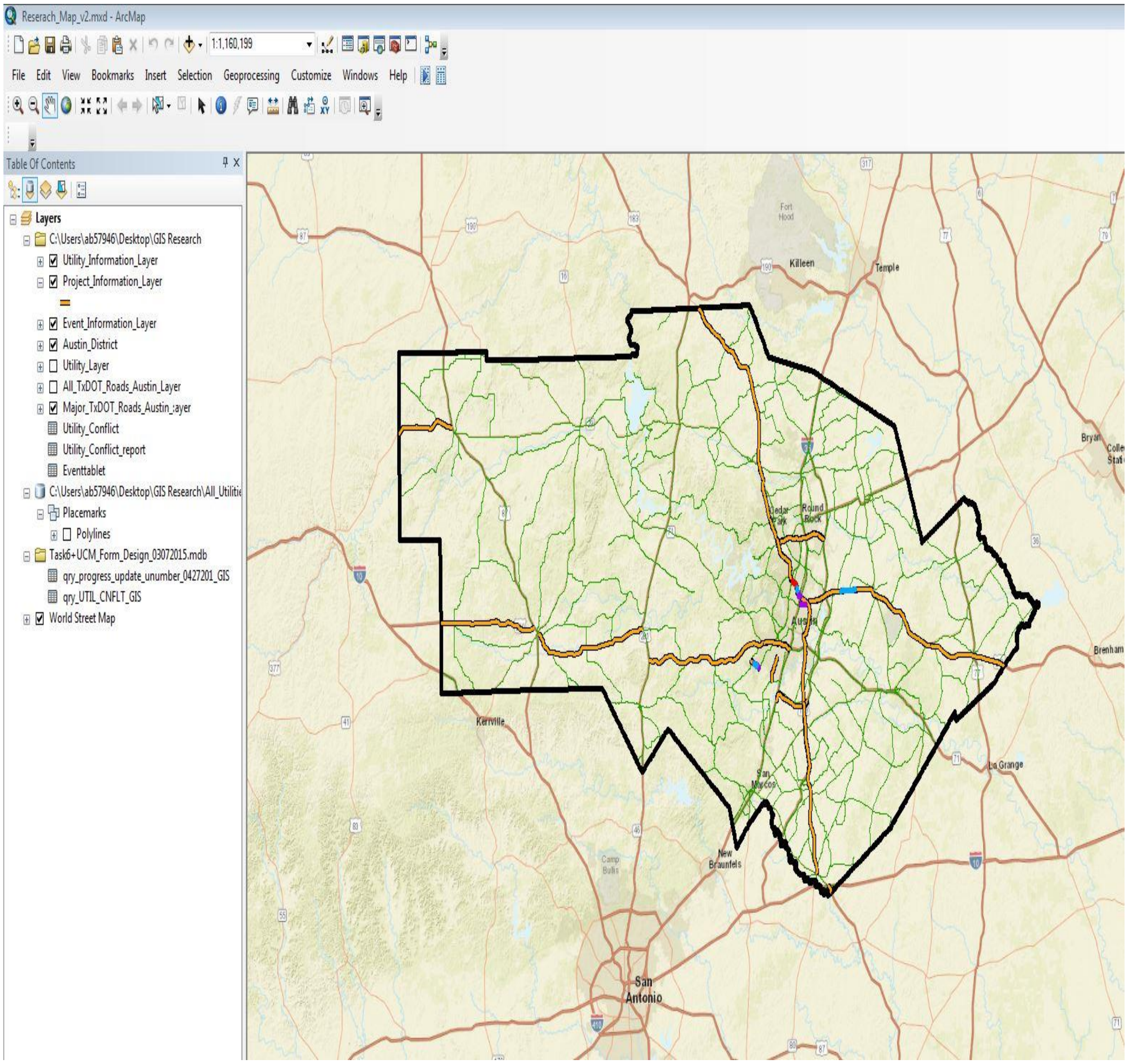


Figure 6-9: Visualization Tool Developed Using ArcGIS and MS Access Based Utility Adjustment Tool

Chapter 7 Conclusions and Recommendations

This research focused on developing a methodology that can help the Utility Coordinators in TxDOT visualize the utility adjustment process. A relational database system integrated with GIS was developed that can store utility tracking information efficiently and has a visually pleasing user interface for displaying results. This section provides us the conclusions derived from the research, discusses the benefits and limitations of the tool and suggests future steps in utility adjustment and tracking.

CONCLUSIONS

This section of the chapter discusses conclusions derived from the successful completion of the research objectives:

(1) Utility Adjustment process is a lengthy process and lot of communication is required with all the parties involved in the relocation process. There are not many methods available that help in organizing and storing all the communication and coordination efforts performed by the TxDOT utility coordinators. This methodology helped the utility coordinators to keep track of the utility adjustment process.

(2) The main aim of developing this methodology was to help utility coordinators to contextualize visually; all the utility information stored by them. The utility coordinators can prioritize the adjustment activities on various projects simply by looking at the geographical maps displayed in the GIS based map environment. Major highways and smaller roads are displayed separately so that utility coordinator has clear idea which utilities need to be adjusted with priority.

(3) There are other systems in TxDOT that use GIS as their platform; this methodology has been developed keeping in mind those systems. The data

attributes, coordinate systems, and the symbology of attributes are similar to the other systems. The information in the system developed using this methodology can easily be used by other systems based on GIS platform.

BENEFITS AND LIMITATIONS

The Utility Adjustment visualization system, developed specifically for Utility coordination and adjustment process has many benefits and a few limitations too. Benefits and limitations of this system have been discussed below.

Benefits

(1) The utility related information is stored in a well-organized repository rather than multiple excel sheets across different computer systems. This helps in maintaining data integrity and keeps the information well organized.

(2) This methodology helps to store information that can be reused over multiple projects and hence reduces the amount of work for the utility coordinator.

(3) The methodology is very flexible and with slight adjustments can be used across different TxDOT districts or even different state DOTs.

(4) This methodology helps displaying spatial data of highways and utilities on GIS maps for visualization purpose.

(5) The user can generate reports simply by selecting the utilities or highways on the GIS maps. These reports are also very visually appealing.

(6) This methodology is not dependent on a specific GIS-based platform. The methodology can be used to develop a visualization system from different GIS software available in the market

Limitation

(1) The multiple users across different network system usability issues have not been scaled yet. Moreover, only one user can make changes to the data in the system at one time; multiple users editing the data in the system at the same time is not possible due to IT constraints.

(2) The visualization capability is limited due to the amount of spatial data available for utilities with TxDOT or City of Austin. For a more robust visualization system, more spatial data needs to be made available for developing shapefiles that will display the complete network of different utility facilities within the Austin District jurisdiction.

(3) The technical aspect of utility adjustment was not taken into account while developing this methodology.

FUTURE RESEARCH RECOMMENDATION

(1) There are many project information management systems being used by TxDOT. Integrating GIS-based visualization with these systems should be considered in future. Integrating these systems will further reduce data entering for the utility coordinators. The ROW information can also be displayed in the GIS environment along proposed utility relocations if the ROWIS system can be integrated. The project related information can directly be imported from DCIS system rather than the utility coordinator entering all this information in the database.

(2) The visualization system should not be limited to individual districts; rather the methodology should be customized so that all the districts can use it. Customizing the methodology to reflect a utility coordination process for all the districts can be done in future.

(3) Currently, the methodology does not support multi user environment. The GIS maps developed for this research can be further developed for the web-based GIS browser so that multiple users across different networks and districts can visualize the utilities easily.

Bibliography

Arboleda, Carlos A, Hyung Seok Jeong, Dulcy M Abraham, and Sanjiv Gokhale. 2004. "Evaluation, Analysis, and Enhancement of INDOT’s Utility Accommodation." Final Report, West Lafayette.

Chou, Chien-Cheng. 2007. "Decision support model for the combined transportation and utility construction strategy." Ph.D. Thesis.

Code of Federal Regulations. 1999. 23 - Highways. Washington D.C.: U.S. Government Publishing Office.

Ellis, Ralph D: Thomas. 2002. The Root Causes of Delays in Highway Construction. Transportation Research Board.

Ellis, Ralph D: Thomas, Randolph. 2002. The Root Causes of Delays in Highway Construction. Transportation Research Board.

Ellis, Ralph. 2003. "DEVELOPMENT OF IMPROVED STRATEGIES FOR AVOIDING UTILITY-RELATED DELAYS DURING FDOT HIGHWAY CONSTRUCTION PROJECTS ."

ESRI. 2016. ArcGIS for Desktop. http://desktop.arcgis.com/en/arcmap/10.3/map/reports/exportreport.htm.

—. 2016. "Arc-GIS for Desktop." Arc-GIS for Desktop. http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/connecting-to-a-microsoft-access-database.htm.

—. 2016. Joins and Relates. http://pro.arcgis.com/en/pro-app/help/data/tables/joins-and-relates.htm.

Hura, Gurdeep S, and Mukesh Singhal. 2001. Data and Computer Communications. CRC Press.

Kraus, Edgar, Ryan Brown Cesar Quiroga, and Charles Stevens and Nichlos Koncz. 2007. "Development of Utility Conflict Management Tool." Technical Report.

Munson, John N, Patricia L Lees, Kenneth G Blom, Jerome S Nelson, C. Paul Scott, and James Anspach. 2000. Avoiding Utility Relocations. Federal Highway Administration (FHWA).

O'Connor, James T, Edward G Gibson, Stephen M Hedemann, Rei-Lin G Chang, and Wai K Chong. 2006. "Duration Quantification and Opportunities for Improvement in the Texas Department of Transportation's Utility Adjustment Process ."

Peter, Rob, and Carlos Coronel. 2007. "Database Systems: Design, Implementation, and Management."

Quiroga, Cesar, Kraus Edgar, Scott Paul, Tom Swafford, and Phillip Meis. 2012. Identification of Utility Conflicts and Solutions. Transportation Research Board.

Roberts, G. W, O Ogundipe, X. Meng, and Jean Montillet. 2007. Positioning Buried Utilities using an Integrated GNSS approach. Sydney: IGNSSS.

n.d. SHRP 2 Trenchless Technology Center. http://138.47.78.37/sault/Uldb_List.asp?methods=1&mthdcat=Array1.

SHRP. 2012. SHRP 2 Tools for Underground Utility Location, Data Collection and Analysis. Washington DC: Transportation Research Board.

Texas Department Of Transportation. 2013. Project Development Process Manual. Texas Department Of Transportation.

Texas Department Of Transportation. 2014. "Utility Manual."

Thitimakorn, T., N. Kampananon, S. Kupongsak, and n. Jongjaiwanichkit. 2016. "Sub-surface void detection under the road surface using GPR, a case study in Bangkok, Thailand." Aug.

Transportation Research Board. 1984. " Reducing Construction Conflicts Between Highway and Utilities."

Transportation Research Board. 2003. "UTILITY RELOCATION AND ACCOMMODATION ON FEDERAL-AID HIGHWAY PROJECTS."

Trimble. 2016. R10 User Manual.

TXDOT. 2014. "Project Development Process Manual."

The United States General Accounting Office. 2002. "Highway Infrastructure: Preliminary Information on the Timely Completion of Highway Construction Projects."

Zlatanova, Sisi, and Jantien Stoter. 2006. "The Role of DBMS in the new Generation GIS architecture." In Frontiers of Geographical Information technology, by Sisi Zlatanova and Jantien Stoter, p 155 - 180. Springer Berlin Heidelberg.